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**WINCLR: A Computer Code for Heat Transfer
and
Clearance Calculation in a Compressor
- A Manual**

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EXECUTIVE SUMMARY

One of the concerns during flight operations in inclement weather involving rain and hail ingestion is the possibility of an appreciable change in compressor casing clearance. The compressor clearance is a design parameter selected on the basis of minimizing performance loss and the possibility of casing rubbing by the blades under various, normal operating conditions. In some engines an active control is incorporated to reduce the clearance change to a minimum. During rain and hail ingestion, there is heat transfer between the working fluid and the three parts of a compressor, namely the casing, the blades, and the rotor. Such heat transfer causes changes in the physical dimensions of the three parts and thus there can be either a positive or a negative change (an increase or a decrease) in clearance. In the current report, a computer code, WINCLR, is described, that has been established for determining the possible change in casing clearance under given conditions of compressor operation and water ingestion.

The details of the physical basis for setting up the WINCLR code are provided in a companion report entitled "WINCLR: A Computer Code for Heat Transfer and Clearance Calculation in a Compressor: A Detailed Description". The current report presents only a description of the code along with an illustrative case on application.

The determination of heat transfer between the working fluid and the metal parts of a compressor at any location in the compressor requires a knowledge of the state of the working fluid in the compressor at that location. However, the state of the working fluid depends on the initial conditions, the performance of the compressor up to that location, and also, significantly, the heat transfer between the working fluid and the metal parts. Thus there is a nonlinear interaction between the performance of the compressor and the heat transfer process. The PURDU-WINCOF I code has been suitably modified for taking into account heat exchange with the metal parts.

The WINCLR code and the modified WINCOF I code are set up to operate interactively. First the WINCOF I code is utilized to obtain the performance of the compressor neglecting the heat transfer to the metal parts. Next, the heat transfer to the metal parts is determined. The performance of the compressor is then determined accounting for the heat transfer using the

modified WINCOF-I code. Finally, the heat transfer and the performance calculations are repeated iteratively until the heat transfer is established to a desired accuracy.

The resulting casing clearance is obtained by determining the changes in the physical dimensions of the casing, the blades, and the rotor, and by summing the changes suitably.

An illustrative case is presented for the case of a generic high pressure ratio compressor operating under certain conditions of ingestion. It is of interest to note that the heat transfer calculations do not require more than one iteration, and that the clearance in the front stages of the multistage compressor is increased causing substantial changes in performance, while the clearance in the back stages is decreased leading to a possible contact and rubbing between the blades and the casing.

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1. INTRODUCTION

Compressor casing clearance is an important parameter in the operation of a flight engine. When the clearance becomes small there is the possibility of a contact between blades and the casing wall and, hence, rubbing. In rare cases the rubbing may be intense enough to cause melting, local welding and tear, causing severe damage to the blades involved, or burning, for example with titanium in the blades. When the clearance becomes large, there is a substantial increase in the losses in the performance of the compressor. An optimum value of clearance has largely remained a concept, especially in view of the variety of conditions in which an engine may be required to operate. However, a controlled clearance has become practical in recent times. Such developments require a knowledge of the manner in which the casing clearance in an engine of given materials of construction varies with given ambient atmospheric and operating conditions. The variation may be determined with respect to, for example, the value of the clearance under cold conditions as manufactured or under an operating condition such as the cruise condition. One method of undertaking the determination of casing clearance is through measurements under different conditions. Although attempts are underway to measure blade clearance even for individual blades in a multistage machine, it is obviously impractical to set up all possible environmental conditions. Therefore, there are extensive efforts to develop analytical-computational methods by means of which reasonable estimates can be made of the casing clearance under various conditions. The interest in the current report is in the development of such a computational method for an operating condition involving water ingestion into the engine the compressor of which is under consideration.

Water ingestion into an engine, such as during flight in a rain storm, causes the inlet and the compressor system to operate with an air-water mixture, some of the water being in liquid form. The air-water mixture passes through the annulus of the compressor and therefore causes heat exchange with the blades. In addition, the air-water mixture may enter the cooling passages of the rotor and thus the rotor temperature distribution could become different from what it would be during operation of the engine under normal circumstances when the cooling passages carry only air. Finally, during passage of the air-water mixture through the compressor annulus, water becomes centrifuged towards the casing wall and a film becomes formed at the casing wall. This gives rise to a change in the casing wall temperature.

The casing clearance is nothing but the difference in physical dimension of the casing and the rotor with the blade. Thus the clearance and its change can be determined if the dimensions of the casing, the rotor blade, and the rotor are known under different conditions. This is the method normally employed for establishing the clearance. In applying the method to an actual engine compressor, there are several complexities in the compressor and the engine, not necessarily related to the heat load and transfer of the three main parts of the compressor (the blades, the rotor and the casing), but nevertheless entering into the fluid flow dynamics and thermal balance of the system. Including such complexities is an extremely difficult task. In fact, while the basic methodology of determining the clearance is simple in principle, the detailed design of the engine is, in various respects, specific to the class of engine and, therefore, the method for a detailed estimation of clearance becomes specific at least to the class of the engine. The methodology developed and in the current report includes only the three basic components of the compressor and does not take any account of the complexities that are typical of a modern flight engine.

The main concern in determining the thermal load and the resulting physical dimension of the three main parts of a compressor during operation with an air-water mixture is that the working fluid is an air-water mixture. The two-phase nature of the fluid introduces a variety of complexities in flow and heat transfer processes. For example, in the case of the rotor it is not clear if the cooling flow passages operate with the same two-phase fluid mixture as in the annulus. The fluid dynamics of fine passages with two-phase flow is not understood in all aspects. The methodology for determining the clearance in the case of operation with air-water mixture is developed here under a series of assumptions and approximations. The methodology is suitable at best for obtaining estimates of clearance. The main outcome of the development of the methodology presented here is a framework for analyzing and calculating the clearance.

1.1. Description of the Methodology

Details of the methodology are presented in Ref. 1, along with the necessary background on various relevant aspects of compressor cooling schemes, analytical-computational methods for estimating loads, and the features of flow and heat transfer that need to be taken into account in the case of a two-phase working fluid. Here a brief outline of the methodology is presented as background to the discussion of the computational code developed for determining the clearance and its changes in different circumstances.

It may be useful to note that the performance of a compressor is affected by the heat transfer between the working fluid and the metal structure of the compressor. In order to establish the heat transfer in a stage of a compressor one needs to know the thermal state of the working fluid in the stage. However, the thermal state itself undergoes changes on account of heat transfer. In a multistage machine the changes in one location affect the performance everywhere downstream. It, therefore, becomes necessary to carry out the calculation of heat loads and thereby the clearance through an iterative procedure that includes the determination of the performance of the compressor in each iteration step.

In the methodology developed for the determination of clearance in the case of water ingestion, the procedure is the same as described above. A code has been developed for the determination of heat loads and clearance, the WINCLR code, that depends upon a knowledge of the performance of the compressor under a set of water ingestion and operating conditions.

The performance of a compressor operating with an air-water mixture can be determined utilizing the WINCOF-I code (Ref. 2). However, the WINCOF-I code, while it accounts for interphase heat and mass transfer, does not account for heat transfer between the working fluid and the metal structure of the compressor. In view of this, the WINCOF-I code has been modified to account for such heat transfer.

The WINCLR code is designed so as to work interactively with the modified WINCOF-I code. The procedure is shown schematically in Fig. 1. The application of the procedure is illustrated in the following first to a single stage unit and then to a multi-stage unit.

1.1.1. Application to a Single-Stage Unit

It may be recalled that the WINCOF-I code is written for a single-stage unit. In the case of a multi-stage unit, the WINCOF-I code is utilized adopting the so-called stage-stacking procedure. The modified WINCOF-I code, that incorporates heat transfer to the metal parts of the unit, is also written for a single-stage unit and a stage-stacking procedure for use in the case of a multi-stage unit.

The methodology for the determination of clearance changes in the case of a single-stage machine may be summarized as follows with reference to the scheme shown in Fig. 1:

- (i) The modified WINCOF-I code is utilized to determine the performance of the compressor stage under given conditions of air-water mixture at entry and operation, without including heat transfer to the metal parts.
- (ii) The WINCLR code is utilized to establish the heat transfer to the metal parts and the resulting value of casing clearance utilizing the stage performance values generated under (i).
- (iii) The modified WINCOF-I code is exercised next to determine the performance of the stage taking into account the heat transfer to the metal parts established under (ii).
- (iv) The WINCLR code is next exercised utilizing the compressor performance established under (iii).

Such an iteration procedure can be continued until the change in clearance is successive iterations is small enough to ensure convergence. In general it is also desirable to establish the trend in convergence of compressor performance.

1.1.2. Application to a Multi-Stage Unit

The procedure is in general identical to that adopted in the case of a single-stage unit. The main difference is that in each step, (i) through (iv), it is necessary to undertake the calculation over the entire multi-stage compressor, while storing performance and heat transfer calculations for each stage in each step so as to be able to recall them in the next step. The main reason for adopting this method of dealing with a multistage machine is that the rotor as well as the casing are single units, and heat transfer calculations for those parts may only be undertaken with respect to the total unit. In other words while stage-stacking is feasible, within its own limitations, for the calculation of compressor performance, heat transfer calculations for the rotor and the casing require a consideration of the total unit. Accordingly, for a multi-stage unit, the performance is calculated using the stage-stacking procedure of the WINCOF-I code and then, the corresponding heat transfer calculations undertaken for the total unit using the WINCLR code. All of the succeeding iterations are carried out in the same fashion.

1.2. Architecture of the WINCLR Code

The WINCLR code may be utilized for heat transfer calculations in the cases of operation with (i) air flow and (ii) air-water mixture flow. Case (i) is sometimes referred to as the dry case. The WINCLR code may be utilized in itself as in combination with the compressor performance code, the WINCOF-I. As stated earlier, the WINCOF-I code is available for use in both the original form, and with inclusion of heat transfer to the metal structure, the later code referred to as the modified WINCOF-I code. The WINCLR code in combination with the modified WINCOF-I code can be utilized to establish the casing clearance in a multi-stage compressor.

The modified WINCOF-I code consists of the original WINCOF-I code with various added routines for the calculation of heat transfer to the metal structure of the compressor and the resulting changes in the performance of the compressor. The input data for the two parts, namely the original WINCOF-I code and the added routines in the modified WINCOF-I code, have been organized separately. The input data for the original WINCOF-I code are provided in files, for example, listed as "case 1-inp". The input data for the modified WINCOF-I code are provided in files, for example listed as "case 2-inp". The input data may, thus, be used without entering the thermal load and casing clearance programs, when necessary. The input data may also be used along with the thermal load and casing clearance programs.

In Fig. 2 a two-stage compressor is shown schematically with a rotor, a casing, and two stages of blading with an IGV row ahead of the first stage. The figure also illustrates the representation of the unit with 19 nodes each encompassing a distinct part or zone of the compressor unit.

Among the three parts of the compressor, the rotor is the most complicated considering the manner in which its cooling is designed in practice. The complexity becomes considerably greater in the case in which the working fluid is a mixture of two phases, such as the air-water mixture. The manner of entry and flow of such a mixture in the cooling passages of the rotor present several ambiguities. In order to proceed, the rotor or disk cooling has been considered in the WINCLR code in terms of four, reasonably well-defined cases, namely: (i) The rotor disk is not internally cooled; (ii) the rotor disk is internally cooled with dry air; (iii) the rotor disk is internally cooled with air-water mixture of the same type as at entry; and (iv) the rotor disk is

cooled with a stagnant body of air-water mixture, which may become replenished in total periodically. The input data for the four cases are given as "blheat 1-inp", "blheat 2-inp", "blheat 3-inp", and "blheat 4-inp", respectively. In each case, a different type of thermal node structure is required. For example, the node-distribution given in Fig. 2 and also, Table I, applies to case (i). In case (iv), the number of nodes remains the same as in case (i) when the cooling fluid is not replenished; however, when there is a replenishment of the fluid, the temperature of the cooling fluid periodically changes and hence, an additional node is required per stage of the compressor unit. Thus a total of 21 nodes becomes necessary, as shown in Fig. 3 for the case of the two-stage compressor. In general, the number of thermal nodes needed for a compressor with N stages is $[(N \times 7) + 5]$ for all cases, except in the case (iv) where the cooling fluid may be undergoing replenishment when the number of thermal nodes required becomes $[(N \times 8) + 5]$. An integer, called "NROTCIS" has been introduced in the program to identify the various cases.

1.3. Outline of the Report

Section 2 deals with a brief description of the WINCLR code. The next section, 3, provides a test case, and finally in the last section a brief discussion is presented.

Table 1. List of various elements

Type of element	Where the type is used	No. of adj. nodes (mm,mf)
1	disk	3(1,2)
2	rotating tube or shaft	4(2,2)
2	rotor rim (extern+intern. cooling)	4(2,2)
3	rotating tube or shaft	4(3,1)
4	rotating tube or shaft	3(2,1)
5	rotating tube or shaft	3(3,0)
6	vane or rotor blade (no intern.cool.)	2(1,1)
7	vane or rotor blade (with intern.cool.)	3(1,2)
8	bore node	1(1,0)
9	metal/rim/casing node(4 adj.metal nodes)	4(4,0)
10	rim node(extern.fluid,intern.metal node)	4(3,1)
11	rim node(extern.metal,intern.fluid node)	4(3,1)
12	casing(extern+intern.fluid)	4(2,2)
13	casing(extern.fluid+intern.solid)	4(3,1)
14	casing(extern.solid+intern.fluid)	4(3,1)
15	rotor disk (without intern.cooling)	2(1,1)
16	rotor disk (with intern.fluid node)	3(1,2)

2. DETAILS OF THE WINCLR CODE

The WINCLR code is written in Fortran 77. A description of the code is given in this section, while the details are given in Appendices I through VI to this report.

2.1. List of Subroutines

The list of subroutines is given in Appendix A to this report.

2.2. Detailed Description of Subroutines and External Functions

A detailed description of the subroutines and external functions is given in Appendix AI to this report.

2.3. Program Source Listing for Modified WINCOF-I Code

The program source listing for the modifications made to the original WINCOF-I code is given in Appendix AII to this report.

2.7. Input And Output Files

As mentioned in section I, the input data are organized in two groups as follows:

- A. Compressor performance data (original WINCOF-I code); and
- B. Nodal temperature and blade clearance.

In group A, the following input files are available:

- A1: case1.inp - for dry air; and
- A2: case2.inp - for air with 4 percent water in droplet form.

In group B, the available input files are as follows:

- B1: blheat1.inp - for solid rotor disk;

- B2: blheat2.inp - for rotor disk internally cooled with dry air in bore channel;
- B3: blheat3.inp - for rotor disk internally cooled in bore channel with air-water mixture; and
- B4: blheat4.inp - for rotor disk internally cooled with intermittently renewed air-water mixture.

In addition one can have additional options from keyboard:

- O1: water film/no water film outside the casing; and
- O2: the state variables of the fluid (air or air-water mixture) in the compressor blade channel is affected/not affected due to heat transfer from hot metal components in the neighborhood of the blade channel fluid.

3 UTILIZATION OF WINCLR CODE

The WINCLR code consists of two parts: (i) related to the modified WINCOF-I code, and (ii) the thermal load and clearance calculation part. In order to illustrate the use of the code, a test case is provided consisting of a two-stage compressor with a row of IGV. It may be recalled that the original WINCOF-I code includes calculations of performance at the design point of the compressor under consideration and, also, the calculation scheme for the off-design performance at desired off-design conditions. When calculations of performance are desired at off-design conditions, they are done for each set of off-design conditions following calculation at the design point. This procedure is left unaltered in the modified WINCOF-I code.

In this section, the utilization of the WINCLR code is given with data preparation, and compilation, linking and running of the code. The utilization of the code may be for a compressor under consideration, or for establishing the operation of the code using the given test case.

The listing of input data files for the test case, consisting of 6 files for different options, is given in Appendix A through D to this report. The listing of output data files for the test case, consisting of 6 files for different options, is given in Appendix E to this report. Finally, the sample data for the thermal load and clearance part of the program are given in Appendix F to this report.

3.1 Test Case

The test case included to illustrate the use of the code is that of a 2-stage compressor with a row of IGV. The details of the compressor are the same as provided in Ref. 2.

It is assumed that the outside surface of the compressor casing remains dry even when considering air-water mixture flow through the compressor.

The input and output files for the test case are given below.

<u>Input files</u>	<u>Output files</u>
A1 + B1	case1.out+blheat1.out
A2 + B1	case2.out+blheat2.out
A2 + B2	case3.out+blheat3.out

3.2. Data Preparation

For both WINCOF-I data and for thermal load and blade clearance data subroutines have been provided for interactive data input. For the latter the thermal model of a nodal element consists of a centroid mass node, for which one needs the product of the mass and the specific heat. The mass mode has heat paths to adjacent element nodes. In the present study one to four adjacent nodes have been used. In some cases, where, because of the geometry, there is no heat flux in a particular direction, one has to take a decision about placement of the centroid mass node. For example for flow within a cylindrical tube the dominant heat flow is in the radial direction, for which the heating surface is obtained from an arbitrarily considered axial length and azimuthal angle (unit axial length, unit radian of azimuthal angle), and the heat flux path length is half of the hollow cylinder (tube) thickness; the mass can be calculated from the volume, which, in turn, is obtained from the axial length, azimuthal angle and thickness. At the same time the external surface area of a blade or the rotor disk may be evaluated as the total external surface, but the centroid node can be placed at the center of gravity determined from the area distribution in the axial direction.

The casing is considered here as a cylinder of given thickness distribution. It is assumed to be subject to heat transfer relative to the fluids both on the inner and the outer surfaces.

In the case of blades, it is assumed that there is no internal cooling. The main concern is with the area exposed to the air-water mixture. This can be determined based on the blockage.

In the case of the rotor, cooling may often be arranged in repetitive sectors over the disk area. In other words, the cooling scheme for a rotor may be repetitive over a certain azimuthal angle. For example, there may be a single passage of fluid covering a sector of 5 blades. Care is then required in determining the centroid node in the rotor.

For the case of the 2-stage compressor considered as the example case, the relevant heat capacity, interface surface area, and heat flux specific path length have been compiled and are given in Tables 2.1 to 2.4 for case (i), that is rotor without internal cooling, and Tables 3.1 to 3.3 for cases (ii), (iii) and (iv), except in case (iv) with replenishment of coolant fluid (or, equivalently, intermittent supply of new coolant fluid); for the latter case the data are given in Tables 4.1 to 4.3.

Table 2.1
Example of a Nodal Topology Matrix
for a two-stage compressor without internal cooling of the rotor

Stage No.	Element No.	Element Type	No. of adj. nodes	Adjacent Node Nos.
IGV	1	2	4	-75,6,-72,-76
	2	12	4	-75,3,-73/-74,-72
	3	14	4	2,9,-73/-74,4
	4	6	2	3,-72
1	5	6	2	6,-71
	6	11	4	1,8,5,7
	7	15	2	6,-76
	8	2	4	6,13,-72,-76
	9	12	4	3,10,-73/-74,-71
	10	14	4	9,16,-73/-74,11
	11	6	3	10,-72
	12	6	2	13,-71
2	13	11	4	8,15,12,14
	14	15	2	13,-76
	15	2	4	12,-75,-72,-76
	16	12	4	10,17,-73/-74,-71
	17	14	4	16,19,-73/-74,18
	18	6	2	17,-72
	19	12	4	17,-75,-73/-74,-72
Post				

Meaning of negative nodes:

- 71: external flow past rotor blades
- 72: external flow past stator blades.
- 73: flow outside casing.
- 74: effective heat transfer coefficient very large (for example, 10^8).
- 75: gradient = 0 (effective heat transfer coefficient = 0).
- 76: flow external to the rotor disk.

Table 2.2
Example of a Nodal Topology Matrix for a two-stage compressor
with internal cooling of the rotor by dry air or air-water mixture

Stage No.	Element No.	Element Type	No. of adj. nodes	Adjacent Node Nos.
IGV	1	2	4	-75,6,-72,-76
	2	12	4	-75,3,-73/-74,-72
	3	14	4	2,9,-73/-74,4
	4	6	2	3,-72
1	5	6	2	6,-71
	6	11	4	1,8,5,7
	7	16	3	6,-76,-77
	8	2	4	6,13,-72,-76
	9	12	4	3,10,-73/-74,-71
	10	14	4	9,16,-73/-74,11
	11	6	2	10,-72
	12	6	2	13,-71
	13	11	4	8,15,12,14
	14	16	3	13,-76,-77
2	15	2	4	12,-75,-72,-76
	16	12	4	10,17,-73/-74,-71
	17	14	4	16,19,-73/-74,18
	18	6	2	17,-72
	Post	19	12	17,-75,-73/-74,-72

Meaning of negative nodes:

- 71: external flow past rotor blades
- 72: external flow past stator blades.
- 73: flow outside casing.
- 74: effective heat transfer coefficient very large (for example, 10^8).
- 75: gradient = 0 (effective heat transfer coefficient = 0).
- 76: flow external to the rotor disk.

Table 2.3
**Example of a Nodal Topology Matrix for a two-stage compressor
with internal cooling of the rotor by intermittent stagnant air-water mixture.**

Stage No.	Element No.	Element Type	No. of adj. nodes	Adjacent Node Nos.
IGV	1	2	4	-75,6,-72,-76
	2	12	4	-75,3,-73/-74,-72
	3	14	4	2,9,-73/-74,4
	4	6	2	3,-72
1	5	6	2	6,-71
	6	11	4	1,8,5,7
	7	17	3	6,-76,-77(12)
	8	2	4	6,14,-72,-76
	9	12	4	3,10,-73/-74,-71
	10	14	4	9,17,-73/-74,11
	11	6	2	10,-72
	12	8	1	-77(7)
	13	6	2	14,-71
	14	11	4	8,16,13,15
2	15	17	2	14,-76,-77(20)
	16	2	4	14,-75,-72,-76
	17	12	4	10,18,-73/-74,-71
	18	14	4	17,21,-73/-74,19
	19	6	2	18,-72
	20	8	1	-77(15)
	Post	21	12	4
				17,-75,-73/-74,-72

Meaning of negative nodes:

- | | |
|---|--|
| -71: external flow past rotor blades | -75: gradient = 0 (effective heat transfer coefficient = 0). |
| -72: external flow past stator blades. | -76: flow external to the rotor disk. |
| -73: flow outside casing. | -77: internal cooling of rotor disk. |
| -74: effective heat transfer coefficient very large (for example, 10^8). | |

Table 3.1
Heat capacity and interface surface area

Stage	Elem.	No. of	M_i	$M_i c_i$	S^{ij} [m ²]
	No.	adj. nodes	[kg]	[J/K]	
IGV	1	4	0.5249	241.45	9.252e-4,9.252e-4,2.786e-3,2.4663e-3
	2	4	0.1802	162.19	2.628e-3,2.628e-3,1.402e-3,1.226e-3
	3	4	0.2272	204.53	2.628e-3,2.628e-3,1.768e-3,1.546e-3
	4	2	0.0264	13.70	1.546e-3,1.035e-2
1	5	2	0.0658	34.17	1.352e-3,2.119e-2
	6	4	0.2510	115.40	9.252e-4,9.252e-4,1.352e-3,1.158e-3
	7	2	0.2596	119.43	1.158e-3,3.129e-3
	8	4	0.6091	280.21	9.252e-4,1.182e-3,3.047e-3,2.632e-3
	9	4	0.6500	585.08	2.628e-3,3.461e-3,4.939e-3,4.327e-3
	10	4	0.3940	354.65	5.346e-3,5.346e-3,3.060e-3,2.686e-2
	11	2	0.0566	29.36	2.686e-3,1.1751e-2
	12	2	0.0732	37.99	2.607e-3,2.098e-2
	13	4	0.4870	224.07	1.182e-3,1.182e-3,2.607e-3,2.266e-3
	14	2	0.5260	241.96	2.266e-3,5.118e-3
2	15	4	0.7770	357.65	1.182e-3,1.182e-3,4.145e-2,3.632e-3
	16	4	0.8431	758.84	3.461e-3,3.064e-3,6.545e-3,5.739e-3
	17	4	0.3003	270.30	3.064e-3,3.064e-3,2.334e-3,2.045e-3
	18	2	0.0383	19.88	2.045e-3,1.339e-2
	Post	19	4	0.2100	3.064e-3,3.064e-3,1.634e-3,1.431e-3

Table 3.2
Heat capacity and interface surface area for rotor disk
with internal cooling by air or air-water mixture flow

Stage	Elem.	No. of	M_i	$M_i c_i$	S^{ij}
	No.	adj. nodes	[kg]	[J/K]	[m ²]
IGV	1	4	0.5249	241.45	9.252e-4,9.252e-4,2.786e-3,2.4663e-3
	2	4	0.1802	162.19	2.628e-3,2.628e-3,1.402e-3,1.226e-3
	3	4	0.2272	204.53	2.628e-3,2.628e-3,1.768e-3,1.546e-3
	4	2	0.0264	13.70	1.546e-3,1.035e-2
1	5	2	0.0658	34.17	1.352e-3,2.119e-2
	6	4	0.2510	115.40	9.252e-4,9.252e-4,1.352e-3,1.158e-3
	7	3	1.4260	655.91	6.946e-3,1.877e-2,1.340e-3
	8	4	0.6091	280.21	9.252e-4,1.182e-3,3.047e-3,2.632e-3
	9	4	0.6500	585.08	2.628e-3,3.461e-3,4.939e-3,4.327e-3
	10	4	0.3940	354.65	5.346e-3,5.346e-3,3.060e-3,2.686e-2
	11	2	0.0566	29.36	2.686e-3,1.1751e-2
	12	2	0.0732	37.99	2.607e-3,2.098e-2
2	13	4	0.4870	224.07	1.182e-3,1.182e-3,2.607e-3,2.266e-3
	14	3	2.6030	1197.5	1.180e-3,2.661e-2,1.340e-3
	15	4	0.7770	357.65	1.182e-3,1.182e-3,4.145e-2,3.632e-3
	16	4	0.8431	758.84	3.461e-3,3.064e-3,6.545e-3,5.739e-3
	17	4	0.3003	270.30	3.064e-3,3.064e-3,2.334e-3,2.045e-3
	18	2	0.0383	19.88	2.045e-3,1.339e-2
	Post	19	4	0.2100	3.064e-3,3.064e-3,1.634e-3,1.431e-3

Table 3.3
 Heat capacity and interface surface area for rotor disk
 with internal cooling by intermittently stagnant air-water mixture

Stage	Elem.	No. of		$M_i c_i$	S^{ij}
No.	No.	adj. nodes	[kg]	[J/K]	[m ²]
IGV	1	4	0.5249	241.45	9.252e-4, 9.252e-4, 2.786e-3, 2.4663e-3
	2	4	0.1802	162.19	2.628e-3, 2.628e-3, 1.402e-3, 1.226e-3
	3	4	0.2272	204.53	2.628e-3, 2.628e-3, 1.768e-3, 1.546e-3
	4	2	0.0264	13.70	1.546e-3, 1.035e-2
1	5	2	0.0658	34.17	1.352e-3, 2.119e-2
	6	4	0.2510	115.40	9.252e-4, 9.252e-4, 1.352e-3, 1.158e-3
	7	2	1.4260	655.9	6.946e-3, 1.877e-2, 1.340e-3
	8	4	0.6091	280.21	9.252e-4, 1.182e-3, 3.047e-3, 2.632e-3
	9	4	0.6500	585.08	2.628e-3, 3.461e-3, 4.939e-3, 4.327e-3
	10	4	0.3940	354.65	5.346e-3, 5.346e-3, 3.060e-3, 2.686e-2
	11	2	0.0566	29.36	2.686e-3, 1.1751e-2
	12	1	0.0000	00.00	1.340e-3
2	13	2	0.0732	37.99	2.607e-3, 2.098e-3
	14	4	0.4870	224.07	1.182e-3, 1.182e-3, 2.607e-3, 2.266e-3
	15	3	0.52.60	241.96	1.180e-3, 2.661e-2, 1.340e-3
	16	4	0.7770	357.65	1.182e-3, 1.182e-3, 4.145e-2, 3.632e-3
	17	4	0.8431	758.84	3.461e-3, 3.064e-3, 6.545e-3, 5.739e-3
	18	4	0.3003	270.30	3.064e-3, 3.064e-3, 2.334e-3, 2.045e-3
	19	2	0.0383	19.88	2.045e-3, 1.339e-2
	20	1	0.0000	00.00	1.340e-3
Post	21	4	0.2100	189.15	3.064e-3, 3.064e-3, 1.634e-3, 1.431e-3

3.3. Compilation, Linking, and Running of the Code

As the code is written in FORTRAN-77, compilation and linking can be done with the help of any suitable Fortran-77 compiler, and the executable file operated. The typical sequential steps in running the code are as follows, noting that the code may be in use for examining the test case, or for establishing the casing clearance for a given compressor:

Step 1: The computer writes the following messages:

WINCOF program
updated data input and compressor clearance
Input data to be generated?

If a response is made with "Y" or "y" and <CR> is pressed, the code performs in the interactive data mode. A file name is requested where all of the data are to be stored, as well as the relevant data to be entered. Step 2 is then skipped and one can proceed to step 3. When, however, it is intended to use a data set stored earlier or the data set for the test case, it is sufficient to press <CR>, and proceed to the next step.

Step 2: The computer writes the following:

WINCOF-I Input data file:

One may then write the name of the data file generated earlier, or one of the data files such as "case1, inp", "case2, inp", or "case2b, inp", and press <CR>. The computer then writes

Output data file:

The output data file name is entered, and on pressing <CR>, the WINCOF-I part of the code is exercised.

Step 3: The computer then writes the following:

total number of sweeps:

Table 4.1
Specific length of the elements for rotor disk without internal cooling

Stage No.	Elem. No.	No. of adj. nodes	$\frac{l_s}{m^2 K / W}$
IGV	1	4	4.780e-4, 7.691e-4, 2.771e-4, 2.771e-4
	2	4	1.246e-4, 2.817e-4, 2.493e-4, 2.493e-4
	3	4	2.817e-4, 5.430e-4, 2.493e-4, 3.538e-3
	4	2	3.538e-3, 5.654e-4
1	5	2	5.052e-3, 6.890e-5
	6	4	7.691e-4, 8.263e-4, 5.052e-3, 2.771e-4
	7	2	5.053e-4, 1.940e-4
	8	4	8.263e-4, 9.038e-4, 2.771e-4, 2.771e-4
	9	4	5.430e-4, 5.726e-4, 2.493e-4, 2.493e-4
	10	4	5.926e-4, 6.176e-4, 2.493e-4, 4.707e-3
	11	2	4.707e-3, 7.163e-5
	12	2	4.468e-3, 7.734e-5
1	13	3	9.038e-4, 9.227e-4, 4.468e-3, 2.771e-4
	14	2	5.053e-4, 2.458e-4
	15	4	9.227e-4, 5.541e-4, 2.771e-4, 2.771e-4
	16	4	6.176e-4, 6.489e-4, 2.493e-4, 2.493e-4
	17	4	6.489e-4, 3.026e-4, 2.493e-4, 4.072e-3
	18	2	4.072e-3, 6.344e-5
	Post	19	3.026e-4, 1.246e-4, 2.493e-4, 2.493e-4

Table 4.2
Specific length of the elements for rotor disk
with internal cooling by air or air-water mixture

Stage No.	Elem. No.	No. of adj. nodes	1S [m ² K / W]
IGV	1	4	4.780e-4,7.691e-4,2.771e-4,2.771e-4
	2	4	1.246e-4,2.817e-4,2.493e-4,2.493e-4
	3	4	2.817e-4,5.430e-4,2.493e-4,3.538e-3
	4	2	3.538e-3,5.654e-4
1	5	2	5.052e-3,6.890e-5
	6	4	7.691e-4,8.263e-4,5.052e-3,2.771e-4
	7	3	5.053e-4,1.940e-4,6.541e-5
	8	4	8.263e-4,9.038e-4,2.771e-4,2.771e-4
	9	4	5.430e-4,5.726e-4,2.493e-4,2.493e-4
	10	4	5.926e-4,6.176e-4,2.493e-4,4.707e-3
	11	2	4.707e-3,7.163e-5
	12	2	4.468e-3,7.734e-5
2	13	4	9.038e-4,9.227e-4,4.468e-3,2.771e-4
	14	3	5.053e-4,2.458e-4,7.555e-5
	15	4	9.227e-4,5.541e-4,2.771e-4,2.771e-4
	16	4	6.176e-4,6.489e-4,2.493e-4,2.493e-4
	17	4	6.489e-4,3.026e-4,2.493e-4,4.072e-3
	18	2	4.072e-3,6.344e-5
	Post	19	3.026e-4,1.246e-4,2.493e-4,2.493e-4

Table 4.3
Specific length of the elements for rotor disk
with internal cooling by intermittently stagnant air-water mixture

Stage No.	Elem. No.	No. of adj. nodes	1S [m ² K / W]
IGV	1	4	4.780e-4,7.691e-4,2.771e-4,2.771e-4
	2		1.246e-4,2.817e-4,2.493e-4,2.493e-4
	3		2.817e-4,5.430e-4,2.493e-4,3.538e-3
	4		3.538e-3,5.654e-4
1	5		5.052e-3,6.890e-5
	6		7.691e-4,8.263e-4,5.052e-3,2.771e-4
	7		5.053e-4,1.940e-4,6.541e-5
	8		8.263e-4,9.038e-4,2.771e-4,2.771e-4
	9		5.430e-4,5.726e-4,2.493e-4,2.493e-4
	10		5.926e-4,6.176e-4,2.493e-4,4.707e-3
	11		4.707e-3,7.163e-5
	12		6.541e-5
	13		4.468e-3,7.734e-5
	14		9.038e-4,9.227e-4,4.468e-3,2.771e-4
	15		5.053e-4,2.458e-4,7.555e-5
	16		9.227e-4,5.541e-4,2.771e-4,2.771e-4
	17		6.176e-4,6.489e-4,2.493e-4,2.493e-4
	18		6.489e-4,3.026e-4,2.493e-4,4.072e-3
	19		4.072e-3,6.344e-5
	20	1	7.555e-5
Post	21	4	3.026e-4,1.246e-4,2.493e-4,2.493e-4

The number of sweeps desired is entered, noting that the minimum is one sweep. On pressing <CR>, the computer writes the following:

thermal node distribution?

When it is intended to bypass it, one needs to press <CR>, and then, the WINCOF-I part of the code alone is exercised, and calculations proceed till the execution is completed. When it is desired to exercise the thermal load and clearance part of the code, one may write "Y" or "y", and press <CR> to proceed to the next step.

Step 4: The computer then writes the following:

metal temp.calculations done after every no. of sweeps=

The desired number of sweeps is entered and <CR> pressed.

A sweep here is the same as the sweep in the original WINCOF-I code, namely the calculation of aerodynamic performance of the compressor over the entire compressor, for example from entry to the compressor to the exit of the last stage of a multi-stage compressor.

When it is desired to account for heat transfer to the metal structure of the compressor, the code performs as follows for a chosen number of sweeps:

(i) The performance of the compressor is determined in the first sweep. The performance of each stage of the compressor is stored.

(ii) Heat transfer to the metal structure is determined, over a chosen period of time such as, for example, 0.15 to 0.25, with reference to the temperature of the working fluid as determined in (i) and a value of temperature for the metal structure. Regarding the latter, the metal temperature may be assumed, in the first instance, as the given ambient conditions.

(iii) Entering an inner loop in a sweep, the metal temperature is updated in a series of iterations, each time assuming the working fluid parameters to remain unaltered at the values stored for each stage and accounting for the modified heat transfer. At the end of a certain

number of iterations, such as 30 to 50 over a period of time equal to [(0.1 to 0.2) s X (30 to 50)], it can be expected that an equilibrium is reached between the working fluid and the metal structure, and the temperature of the metal does not undergo appreciable changes.

(iv) Then, the performance of the compressor is determined accounting in each stage of the compressor for heat transfer to the metal. The updated data on performance is stored for each stage.

(v) The calculations in step (iii) are repeated, and using the heat transfer data so determined, the performance calculation of (iv) is repeated. The changes in the performance of the compressor may generally be small in such an iteration, and thus it may not be necessary to repeat the calculations over more than 2 to 5 sets of sweeps.

The computer writes, at the end of this calculation, as follows:

This subroutine helps for use in nodal temperature and clearance package

1. to generate data, and
 2. to retrieve data for calculation.
- choice:

Writing 1 and pressing <CR> leads to step 5, and writing 2 and pressing <CR> to step 6.

Step 5: The computer now writes as follows:

generated data to be stored in file:

Giving the file name and pressing <CR> leads the code to ask for data in the interactive mode, and then one can proceed to step 7.

Step 6: The computer writes as follows:

data retrieved from file:

The name of the data file for temperature distribution and blade clearance may be given, or one may write the name of one of the data files such as "blheat1.inp" supplied.

Step 7: The computer writes as follows:

Type in the following data:

casing air density(kg/m**3);

casing air temp.(K);

airspeed outside casing(m/s);

stagn.temp. of air outside casing(K);

airflow temp.inside rotor(K);

airflow density inside rotor(K);

airflow speed inside rotor(m/s);

delta_temp.(K) needed to compute Grashof number in rotor disk(20); and

water film surface temp.relax.factor(0. to 1.)

The desired data is typed in and <CR> pressed.

The computer then asks as follows:

water film outside casing?

If <CR> is pressed, the code proceeds further till execution is completed. If "Y" or "y" and <CR> are pressed, the temperature of the film outside the casing is requested. When the temperature is given and <CR> pressed, the code proceeds to completion of execution.

4. DISCUSSION

The WINCLR includes two major parts: (i) the modified WINCOF-I code for obtaining the performance of a multi-stage compressor, taking into account heat transfer to the metal structure, and (ii) the thermal load and clearance part.

The WINCLR code can be utilized to determine the performance and the blade clearance in two major options: (i) adiabatic, with no heat exchange between the working fluid and the metal structure of a compressor, and (ii) non-adiabatic, allowing for such heat exchange.

In option (ii), there are several internal options depending upon the manner in which the casing wall and the rotor are required to be taken into account. For the casing wall, the outer surface may be assumed to be covered with air or air-water mixture when the compressor is ingesting an air-water mixture. For the rotor, the rotor build-up and cooling scheme provide various options.

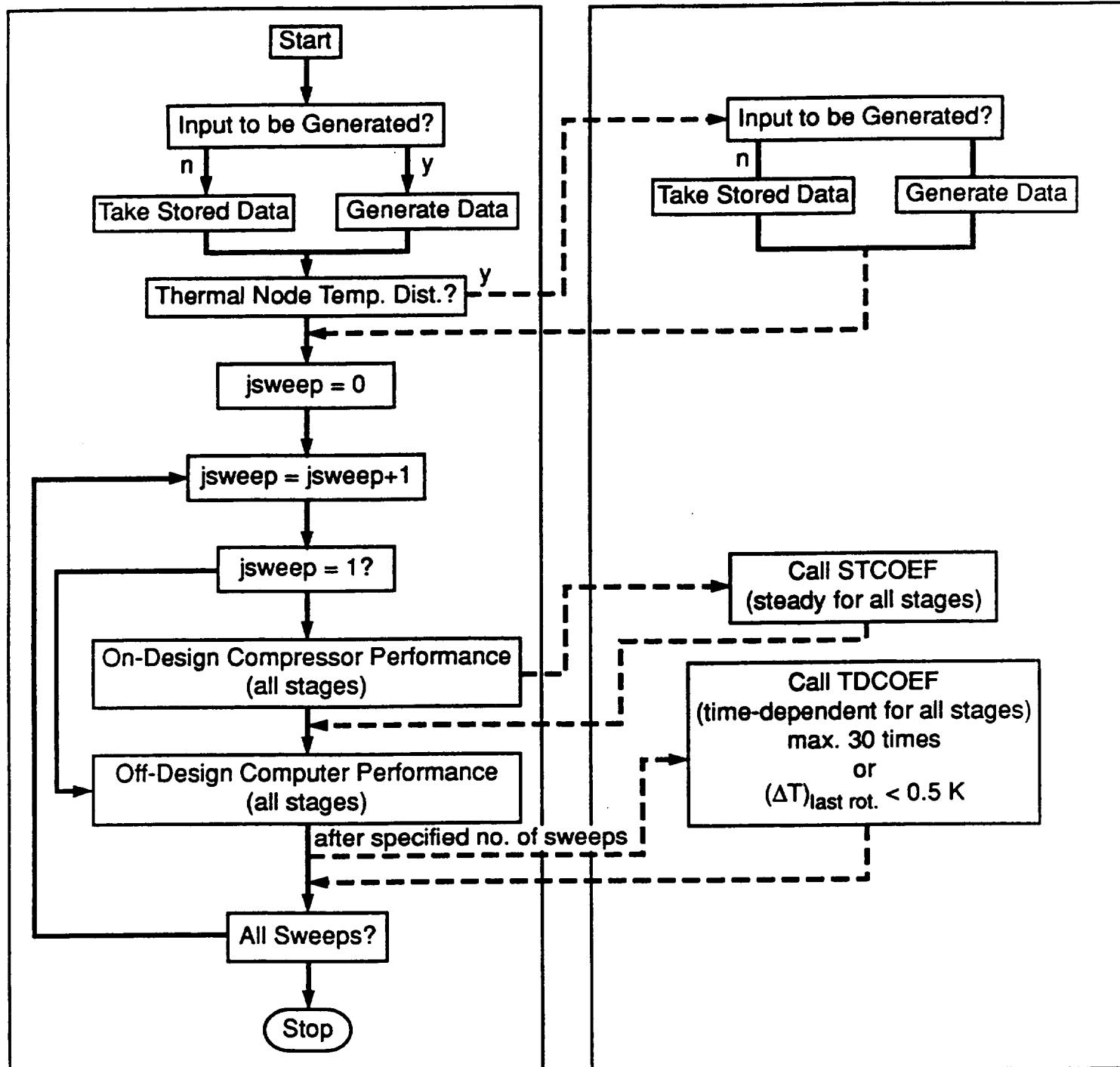
Accounting for heat transfer, as in the non-adiabatic case, it is important to recognize that changes occur both in compressor performance and in clearance. It is shown in Refs. 1 and 3 that, in the case of a multi-stage compressor with a large number of stages, changes in performance are the most dominant in the initial stages, and changes in clearance occur, generally tending to cause rubbing in the later stages.

REFERENCES

1. Bose, T.K., and Murthy, S.N.B., WINCLR: A Computer Code for Heat Transfer and Clearance Calculation in a Compressor: A Detailed Description, Report to be published by NASA Lewis Research Center, 1994.
2. Murthy, S.N.B., and Mullican, A., The WINCOF-I Code: Detailed Description, NASA Contractor Report NASA CR 190779, April 1993.
3. Bose, T.K., and Murthy, S.N.B., Blade Clearance Estimation in a Generic Compressor with Air-Water Mixture Operation, AIAA Paper No. 94-2693, June, 1994.

WINCOF-I

Thermal Node and Blade Clearance



---> = Alternate Path if Thermal Node and Blade Clearance Programmes are Required.

Figure 1. Structure of WINCLR Code.

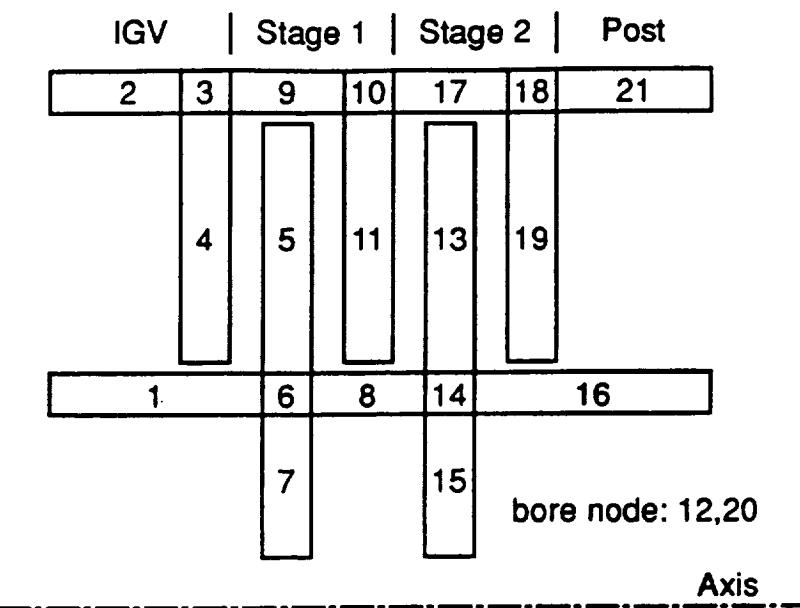


Figure 2. Schematic sketch of a two-stage compressor with rotor disk internal node.

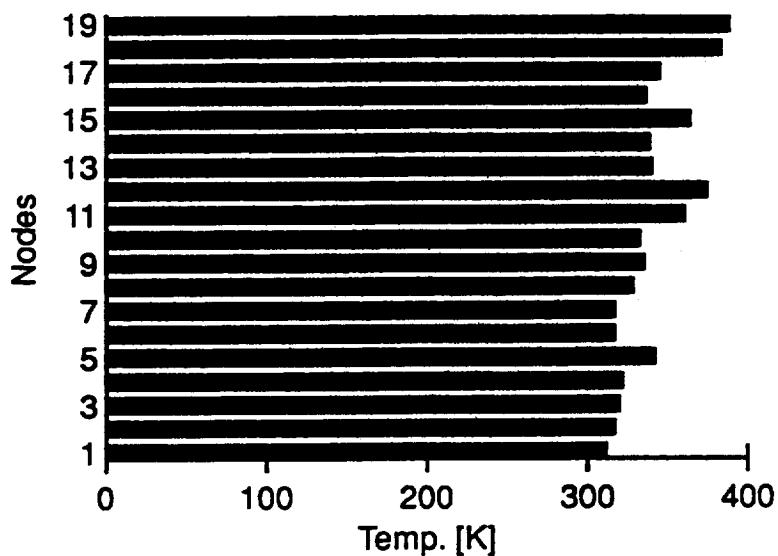


Figure 3. Temperature distribution of various nodes.

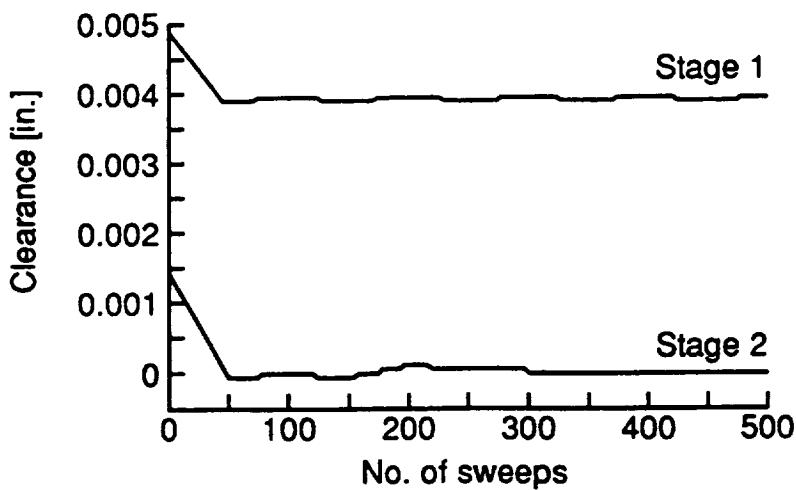


Figure 4. Change in rotor blade clearance due to water ingestion.

Appendix A: List of Subroutines

This list contains the following: names of subroutines and functions of original WINCOF-I; two subroutines to help data-input in interactive mode (designated with superscript \$) for the original WINCOF-I; functions and subroutines for the nodal temperature and rotor blade clearance calculations (designated with superscript #); and a description of what each of these functions and subroutines do.

wicinp\$: data input for WINCOF-I in non-interactive mode
wicspb: stage performance (off-design) for small droplet
wcspbs: part of original wicspb, but only for stator calculations
prince: printing part of original wicspb
wicspc: stage performance (off-design) for large droplet
wicmac: part of original wicspc to compute for stator
wicasd: acoustic speed in two-phase flow
wiced: calculation of equivalent diffusion
wicmtk: calculation of dimensionless momentum thickness
wiclos: total pressure loss coefficient
wicirs: small droplet impingement and rebound in rotor blades
wicirl: large droplet impingement and rebound in rotor blades
wiciss: small droplet impingement and rebound in stator blades
wicisl: large droplet impingement and rebound in stator blades
wicwak: water ingestion into wake of blades
wichet: heat transfer between gaseous phase and droplets
wicmas: mass transfer between gaseous phase and droplets
wicmtr: calculation of mass transfer rate
wicpwb: calculation of vapor pressure
wicnew: to seek new trial value in an iterative procedure
wicbpt: calculation of boiling point
wicsh: calculation of specific humidity
wictan: tangent function
wiccen: spanwise replacement of droplets due to centrifugal action
wicrgv: quantity of vapor centrifuged
wicdmv: compute area that vapor occupies (used by "wicdml" called by "wicrgv")
wicdms: (not called by any routine at present)
wicdml: quantity of large droplets centrifuged (called by "wicrgn")
wicflm: (not called by any routine at present)
wicrgn: water distribution routine
wicdrdg: drag force on droplet
wicsiz: calculation of droplet size (by considering "Stability number")
wicprp: flow properties for gaseous phase
wiccpa: specific heat of air at constant pressure
wiccpb: specific heat of vapor at constant pressure
wicccpc: specific heat of methane at constant pressure
wicgsl: single phase (gas) flow loss
wicsdl: loss due to small droplets to change boundary layer momentum thickness
wicstl: loss due to Stokesian drag in free-stream
wicfml: loss due to film formed on blade surface when large droplets are present
wicrsl: loss due to surface roughness modelling of large droplets
wicspd: design point performance

pldatv: plotting routine (not being used at present)
wicbet: applies normal stator setting to IGV
wicvap: to get correct droplet temperature at very high evaporation rate
msec: help routine to compute gemax by secant method
fpm: auxilliary function for msec
fppm: (not called by any routine)
wicrng: creates a range of flow coefficients
getnm: gets upto 19 strings of 4 characters till "do"
plotit: does scaling, etc. for the plotter (not being used at present)
phimx: maximum value of flow coefficient, depending on rpm fraction
datinp\$: data input for WINCOF-I in interactive mode
htdgen#: data creation/input interactively for node temperature and blade clearance
htexin#: data input non-interactively for node temperature and blade clearance
therex#: blade clearance thermal expansion function
spear#: to extract/add/remove/replace in a sparse matrix
spcrp#: sparse matrix counting and row parameters
spmsol#: general sparse matrix solution
stcoef#: steady state influence cefficients calculation
tdcoef#: time-dependent case to calculate influence coefficients
mixprp#: properties of air+vapor+water (homogeneous mix.)

APPENDIX B: Detailed Description of Subroutines and External Functions

In the following a description is provided of the subroutines and external function generated in connection with the nodal temperature distribution and blade clearance. Each of the subroutines and external functions is presented as follows: (1) Description, (2) Input variables, (3) Output variables , and (4) Usage.

SUBROUTINE DATINP:

(1) Description: The subroutine allows data generation and output it to a file to store away in interactive manner, or if the data has already been generated in another occasion, then to recover it.

(2) and (3) Input and Output variables:

ns number of stages (total)
nsf number of stages (fan)
nslpc number of stage (low pressure compressor)
nshpc number of stage (high pressure compressor)
rrhub(i) rotor inlet radius at hub for i-th stage in inch
rc(i) rotor chord for i-th stage in inch
rblade(i) number of rotor blade for i-th stage
stager(i) rotor stager angle for i-th stage in degree
srhub(i) stator inlet radius at hub for i-th stage in inch
sc(i) stator chord for i-th stage in inch
sblade(i) number of stator blade for i-th stage
stages(i) stator stager angle for i-th stage in degree (i=ns+1 for igv)
sigumr(i) solidity of rotor for i-th stage
sigums(i) solidity of stator for i-th stage
bet2ss(i) stator outlet absolute flow angle at design point for i-th
 stage in degree
fnf fraction of design corrected rotor speed for a particular
 speed
xdin initial water content (mass fraction) of small droplet
xddin initial water content (mass fraction) of large droplet
icent index for centrifugal calculation (icent=1 when xdin=0
 otherwise icent=2)
iicent same as icent
icent=3,iicent=3: no heat and mass transfer
icent=4,iicent=4: no centrifugal action
icent=5,iicent=5: no heat and mass transfer;and
 no centrifugal action
icent=6,iicent=6: no mass transfer
icent=7,iicent=7: no mass transfer;and
 no centrifugal action
icentv index for centrifugal action of vapor
icentv=0: vapor is centrifuged
icentv=1: vapor is not centrifuged
t0g total temperature at compressor inlet in rankin
t0w water droplet temperature at compressor inlet in rankin
p0 total pressure at compressor inlet in lb/ft**2
din initial water droplet diameter in micron(small droplet)
ddin initial water droplet diameter in micron(large droplet)
fnd rotor rotational speed at design speed in rpm

	(fan and low pressure compressor)
fnlpc	rotor rotational speed at design speed in rpm (low pressure compressor)
fndhpc	rotor rotational speed at design speed in rpm (high pressure compressor)
t01d	design value for compressor inlet total temperature
p01d	design value for compressor inlet total pressure
xch4	initial methane content
rhumid	initial relative humidity
fmwa	molecular weight of air (28.964)
fmwv	molecular weight of water vapor (18.016)
fmwc	molecular weight of methane (16.043)
preb	percent of water that rebound after impingement
dlimit	max. diameter for small droplet
gapr(i)	gap between i th stage rotor and i-1 th stage stator
gaps(i)	gap between i th stage stator and i-1 th stage rotor
rttip(i)	rotor inlet tip radius for i-th stage
srtip(i)	stator inlet tip radius for i-th stage
irad	index for radius at which calculation is carried out irad=1: tip irad=2: mean irad=3: hub irad=4: mean for fan and tip for lpc,hpc
rt(i)	rotor inlet radius at which tip performance calculation is carried out.
rm(i)	rotor inlet radius at which mean line performance calculation is carried out.
rh(i)	rotor inlet radius at which hub performance calculation is carried out.
st(i)	stator inlet radius at which tip performance calculation is carried out
sm(i)	stator inlet radius at which mean line performance calculation is carried out
sh(i)	stator inlet radius at which hub peformance calculation is carried out
block(i)	blockage factor for i-th stage rotor
blocks(i)	blockage factor for i-th stage stator
idesin	index for output idesin=1:both stage and overall performance may be printed out idesin=2:only overall performance may be printed out
jcent	index for centrifugal calculation of large droplet jcent=0:large droplets in rotor free streamm are not centrifuged jcent=1:large droplets in rotor free-stream are centrifuged
bet1mr(i)	blade metal angle at rotor inlet for i-th stage
bet2mr(i)	blade metal angle at rotor outlet for i-th stage
bet1ms(i)	blade metal angle at stator inlet for i-th stage
bet2ms(i)	blade metal angle at stator outlet for i-th stage
dsmass	design mass flow rate for fan part (streamtube)
bypass	bypass ratio
pr12d(i)	design total pressure ratio for i-th stage rotor

pr13d(i) design total pressure ratio for i-th stage
etard(i) design adiabatic efficiency for i-th stage rotor
sarea(i) flow area at i-th stage rotor inlet (streamtube)
sareas(i) flow area at i-th stage stator inlet (streamtube)

(4) Usage: CALL DATINP

SUBROUTINE HTDGEN

(1) Description : it is the counterpart of the subroutine DATINP for the nodal temperature distribution and blade clearance part.

(2) and (3) Input and Output Variables:

arnod	surface area of a nodal element
casrad	radius of the casing
dwat	water film thickness inside rotor bore [m]
excfcs	coeff. of expansion for casing
excfr	thermal expansion coefficient for casing
htcap	heat capacity of nodal element
ifan	number of fan stages
imax	number of stages
jmax	maximum number of elements per stage
kmax	maximum number of adjacent nodes per stage
ndmax	array of number of nodes in each stage
ndtop	nodal type and topology matrix
nexcas	casing thermal expansion node number
nexnod	thermal expansion node numbers in each stage
nexpr	no.of nodes considered for thermal expansion in each stage
nrotcs	index for rotor disk cooling
ntex	no.of thermal expansion nodes in rotor stage
permax	cooling channel pressure increase in percent of maximum
radex	radial length to be considered for thermal expansion
splen	heat flow path length divided by heat cond.coefficient
tpawm	rotor disk bore fluid pressure [bar]
trchi	rotor disk bore inside radius [in]
trcho	rotor disk bore outside radius [in]
ttawm	temperature of cooling fluid of rotor disk [K]
tvol	rotor disk bore cooling fluid volume per sector [m ³]
txw0	rotor disk bore cooling fluid water content
xlcso	axial length of elements on casing
xlro	axial length of nodal elements on rotor rim

(4)Usage: CALL HTDGEN

SUBROUTINE HTEXIN

(1) Description: Same as subroutine HTDGEN, except that it is for input of variables only.

(2) and (3):Input and Output variables: Same as in subroutine HTDGEN

(4)Usage: CALL HTEXIN

SUBROUTINE MIXPRP:

(1) Description: mixture properties of air+water+vapor (homogeneous fluid model)

- (2) Input variables: tkin(oK)=temp.in degrees Kelvin,pbar = pressure in bar, xv = kg_vapor/kg_air,xw=kg_water/kg_air
- (3) Output variables: cpm(J/kg-K)=spec.heat,rhom(kg/m**3)=density; xmum(kg/m-s)=dyn.viscosity,xkm(W/m-K)=heat conductivity.
- (4) Usage: CALL MIXPRP (tkin,pbar,xv,xw,cmpr,rhom,xmum,xkm,xkw)

SUBROUTINE SPCRP

(1) Description: Subroutine to find pointers for minimum, maximum and diagonal elements in a row.

(2) Input variables:

i index for row
n order of matrix
lmax maximum value of the location pointer
nemax maximum locations in inl(nemax)

(3) Output variables:

l1 minimum pointer value (Ccolumn no.) in a row
l2 maximum pointer value (column no.) in a row
ld pointer value on the diagonal element in a row
ni no.of data in a row

(4) Usage:

CALL SPCRP(i,n,lmax,nemax,inl,l1,l2,ld,ni)

subroutine spmsol(n,lmax,nemax,inl,vl,rv,c)
c subroutine for general sparse matrix solution
c n=order of matrix, lmax=max.value of pointer, nemax=size
c of two vectors inl(nemax) and vl(nemax), rv(n)=right
c hand side vector,c=working place

SUBROUTINE SPMSOL:

(1) Description: Solver for sparse matrix solution

(2) Input variables:

inl vector of locations of coefficient array
lmax maximum value of locations of coefficient matrix
n order of the coefficient matrix
nemax maximum locations in inl(nemax),vl(nemax)
rv right hand side vector
vl coefficient matrix (destroyed in subroutine)

(3) Output variables:

rv solved vector

(4) Usage:

CALL SPMSOL(n,lmax,nemax,inl,vl,rv,c)

SUBROUTINE SPEAR:

(1) Description: Subroutine to extract/add/remove/replace in a sparse matrix

(2) Input variables:

nemax max.length of inl(nemax),vl(nemax) arrays
i row index for matrix
iflag computation option flag (1-4) for extract/add/remove/replace
inl array of index of values
j column index for the matrix

lcur current pointer position
lmax maximum pointer position
n order of the matrix
vl array of values
x external value for manipulation in subroutine
(3) Output variables:
ier error code
lcur current pointer position
lmax maximum pointer position
vl array of values
x external value for manipulation in subroutine

(4) Usage:

CALL SPEAR(nemax,i,j,n,lcur,lmax,inl,x,vl,iflag,ier)

SUBROUTINE STCOEF:

(1) Description: Computing coefficients for steady solution of heat conduction.

(2) and (3) Input and Output variables:

They are the same as in HTDGEN through COMMON statement. On exit from the subroutine the results are in rrv().

(4) Usage: CALL STCOEF

SUBROUTINE TDCOEF:

(1) Description: Computing coefficients for unsteady solution of heat conduction.

(2) and (3) Input and Output variables:

They are the same as in HTDGEN through COMMON statement. At the time of entry to the subroutine the old temperature values are in rrv() and on exit from the subroutine the results are in rrv().

(4) Usage: CALL TDCOEF

FUNCTION THEREX:

(1) Description: function to calculate rotor-casing clearance in a stage.

(2) Input variable:

istage index for a stage

(3) Output variable:

therex output result

(4) Usage: THEREX(istage)

SUBROUTINE WICINP

(1) Description: Same as subroutine DATINP, except that it is for input of variables only.

(2) and (3): Input and Output variables: Same as in subroutine DATINP

(4) Usage: CALL WICINP

APPENDIX C: Program Source Listing

The following source listing presents only the additions made to the WINCOF-I code to obtain the modified WINCOF-I code.

```
subroutine wicinp
c input data
c ns      number of stages (total)
c nsf     number of stages (fan)
c nslpc   number of stage (low pressure compressor)
c nhpsc   number of stage (high pressure compressor)
c rrhub(i) rotor inlet radius at hub for i-th stage in inch
c rc(i)   rotor chord for i-th stage in inch
c rblade(i) number of rotor blade for i-th stage
c stager(i) rotor stager angle for i-th stage in degree
c srhub(i) stator inlet radius at hub for i-th stage in inch
c sc(i)   stator chord for i-th stage in inch
c sblade(i) number of stator blade for i-th stage
c stages(i) stator stager angle for i-th stage in degree (i=ns+1 for igv)
c sigumr(i) solidity of rotor for i-th stage
c sigums(i) solidity of stator for i-th stage
c bet2ss(i) stator outlet absolute flow angle at design point for i-th
c stage in degree
c fnf      fraction of design corrected rotor speed for a particular
c speed
c xdin    initial water content (mass fraction) of small droplet
c xddin   initial water content (mass fraction) of large droplet
c icent   index for centrifugal calculation (icent=1 when xdin=0
c otherwise icent=2)
c iicent  same as icent
c icent=3,iicent=3: no heat and mass transfer
c icent=4,iicent=4: no centrifugal action
c icent=5,iicent=5: no heat and mass transfer;and
c           no centrifugal action
c icent=6,iicent=6: no mass transfer
c icent=7,iicent=7: no mass transfer;and
c           no centrifugal action
c icentv  index for centrifugal action of vapor
c icentv=0: vapor is centrifuged
c icentv=1: vapor is not centrifuged
c t0g     total temperature at compressor inlet in rankin
c t0w     water droplet temperature at compressor inlet in rankin
c p0      total pressure at compressor inlet in lb/ft**2
c din    initial water droplet diameter in micron(small droplet)
c ddin   initial water droplet diameter in micron(large droplet)
c fnd    rotor rotational speed at design speed in rpm
c           (fan and low pressure compressor )
c fndlpc  rotor rotational speed at design speed in rpm
c           ( low pressure compressor )
c fndhpc  rotor rotational speed at design speed in rpm
```

c (high pressure compressor)
 c t01d design value for compressor inlet total temperature
 c p01d design value for compressor inlet total pressure
 c xch4 initial methane content
 c rhumid initial relative humidity
 c fmwa molecular weight of air (28.964)
 c fmwv molecular weight of water vapor (18.016)
 c fmwc molecular weight of methane (16.043)
 c preb percent of water that rebound after impingement
 c dlimit max. diameter for small droplet
 c gapr(i) gap between i th stage rotor and i-1 th stage stator
 c gaps(i) gap between i th stage stator and i-1 th stage rotor
 c rtip(i) rotor inlet tip radius for i-th stage
 c srtip(i) stator inlet tip radius for i-th stage
 c irad index for radius at which calculation is carried out
 c irad=1: tip
 c irad=2: mean
 c irad=3: hub
 c irad=4: mean for fan and tip for lpc,hpc
 c rt(i) rotor inlet radius at which tip performance calculation
 c is carried out.
 c rm(i) rotor inlet radius at which mean line performance
 c calculation is carried out.
 c rh(i) rotor inlet radius at which hub performance calculation
 c is carried out.
 c st(i) stator inlet radius at which tip performance calculation
 c is carried out
 c sm(i) stator inlet radius at which mean line performance calcu-
 c lation is carried out
 c sh(i) stator inlet radius at which hub performance calculation is
 c carried out
 c block(i) blockage factor for i-th stage rotor
 c blocks(i) blockage factor for i-th stage stator
 c idesin index for output
 c idesin=1:both stage and overall performance may be printed out
 c idesin=2:only overall performance may be printed out
 c jcent index for centrifugal calculation of large droplet
 c jcent=0:large droplets in rotor free streamm are not
 c centrifuged
 c jcent=1:large droplets in rotor free-stream are centrifuged
 c bet1mr(i) blade metal angle at rotor inlet for i-th stage
 c bet2mr(i) blade metal angle at rotor outlet for i-th stage
 c bet1ms(i) blade metal angle at stator inlet for i-th stage
 c bet2ms(i) blade metal angle at stator outlet for i-th stage
 c dsmass design mass flow rate for fan part (streamtube)
 c bypass bypass ratio
 c pr12d(i) design total pressure ratio for i-th stage rotor
 c pr13d(i) design total pressure ratio for i-th stage
 c etard(i) design adiabatic efficiency for i-th stage rotor
 c sarea(i) flow area at i-th stage rotor inlet (streamtube)
 c sareas(i) flow area at i-th stage stator inlet (streamtube)

```

c
c -----
c character*60 title
c -----
c--- pgb 11-21-84. added for doing 6 streamlines. top.
common /cdat2/ rfc(20),sfc(20),bt2ssa(6,20),bt1mra(6,20),bt2mra
&(6,20),bt1msa(6,20),bt2msa(6,20),stagra(6,20),stagsa(6,20),
&etarda(6,20),pr12da(6,20),pr13da(6,20),rca(6,20),sca(6,20),
&sigmra(6,20),sigmsa(6,20),xsarea(6,20),xareas(6,20)
c--- pgb 11-21-84. added for doing 6 streamlines. bottom.
c
common /cdat3/jperfm,rhog(3),rerup,rerlow,resup,reslow
&,preb,rrtip(20),srtpip(20),aaa1,aaa2,aaa3,sarea(20),sareas(20)
&,p(3),tg(3),xa,xv(3),xch4,xw(3),xww(3),xwt(3),tw(3),tww(3)
&,omegs(20),omegr(20),gapr(20),gaps(20),tsg(3),psg(3)
&,rrhub(20) , rc(20) , rblade(20) , stager(20)
&,srhub(20) , sc(20) , sblade(20),stages(20)
&,sigumr(20) , bet1sr(20) , bet2sr(20) , aincsr(20) , adevsr(20)
&,sigums(20) , bet1ss(20) , bet2ss(20) , aincss(20) , adevs(20)
&,utipg(20),utip(20),utipd(20),uou(20),umean(20),uhub(20),u(20),fai
&,area(20),areas(20),uu2(20),utip2(20),umean2(20),uhub2(20),iprint
&,icent,iicent,fmr1(20),fma2(20),idesin,faid
&,ns,nsf,nslpc,bypass,ns1,rt(20),rm(20),rh(20),st(20),sm(20),sh(20)
&,dsmass,aarea(20),aareas(20),pr12d(20),pr13d(20),etard(20)
&,dr(20),ds(20),deqr(20),deqs(20),block(20),blocks(20)
&,bet1mr(20),bet2mr(20),bet1ms(20),bet2ms(20),radi1(20),radi2(20)
&,fairin(20),faiout(20),etasg(20),psid(20),taud(20),sitadr(20)
&,sitads(20),wwd(20),vv(20)
c
common/step/ichord
common/step1/title,nvinam(13,4),nshpc,jend,nwater,icase,irad,jrad,
$idespt,jcent,icentv,xdin,xddin,vairwa,fnf,
$xphi,t0g,t0w,p0,fnd,t01d,p01d,fndlpc,fndhpc,rhumid,fmwa,fmwv,fmws,
$dlimit,predes,temdes,din,ddin
c
common /cdat4/ dvz1(3,20),dvz2(3,20),dvz3(3,20),arout(20),asout
&(20),arin(20),arine(20),aroute(20),asoute(20),ws(3),wmass(3),
$vmass(3),rhoa(3),rhom(3),tb(3),delz(20),etaa(20),dave(20),tdew
$(3),ddave(40),wwmass(3),wtrmass(3),tmass(3),gmass(3),xair(3),
$xmetan(3),xgas(3),ak1(20),ak2(20),ak3(20),zdis(20),clear(20),
$cstara(20),frmmass(3),xf(3),watrgn(20),vaprgn(20),rcase(20),xws
$(20),watrgx(20),uis(20),jflag(20),hhcs(20)
c *-*-*-*-* added by tdh to compute the necessary values
rewind(15)
c -----
c xphi=inlet flow coefficient is selected
c -----
1 format(a)
read(15,1)title
if(jsweep.eq.1)write(16,1)title
read(15,*)xphi

```

```

c -----
c ichord=number of steps per chord used for centrifuging in wicrgn
c -----
c read(15,*)ichord
c -----
c jend=max.number of allowed sweeps (1 for dry air)
c -----
c read(15,*)jend
c -----
c nwater=counter for water cases (=1, dry; =2, wet)
c -----
c read(15,*)nwater
c -----
c icase allows the initial distribution of water to be selected, as
c different cases
c 2-2%, 4-4% (GE case1), 5-GE case 2, 7-GE case 3
c -----
c read(15,*)icase
c   for making the engsim compatable performance maps
c   and to plot the results using the pucc calcomp
read(15,*)ns,nsf,nslpc,nshpc
ns1=ns+1
read(15,*)(rrhub(i),i=1,ns)
do11i=1,3
read(15,*)(rca(i,j),j=1,ns)
11  continue
read(15,*)(rblade(i),i=1,ns)
do13i=1,3
read(15,*)(stagra(i,j),j=1,ns)
13  continue
read(15,*)(srhub(i),i=1,ns1)
do14i=1,3
read(15,*)(sca(i,j),j=1,ns1)
14  continue
read(15,*)(sblade(i),i=1,ns1)
do15i=1,3
read(15,*)(stagsa(i,j),j=1,ns1)
15  continue
do17i=1,3
read(15,*)(sigmra(i,j),j=1,ns)
17  continue
do22i=1,3
read(15,*)(sigmsa(i,j),j=1,ns1)
22  continue
do1151i=1,3
read(15,*)(bt2ssa(i,j),j=1,ns1)
1151 continue
c -- pgb 11-21-84. change so can read in 6 stream lines worth. bottom.
c
read(15,*)fnf
read(15,*)xdin,icent,xddin,iicent,icentv

```

```

read(15,*)t0g,t0w,p0
read(15,*)din,ddin
read(15,*)fnd,t01d,p01d,fndlpc,fndhpc
read(15,*)xch4,rhumid
read(15,*)fmwa,fmwbd,fmwc
read(15,*)preb,dlimit
read(15,*)(gapr(i),i=1,ns)
read(15,*)(gaps(i),i=1,ns)
read(15,*)(rrtip(i),i=1,ns)
read(15,*)(srtip(i),i=1,ns1)
read(15,*)irad
read(15,*)(rt(i),i=1,ns)
read(15,*)(rm(i),i=1,ns)
read(15,*)(rh(i),i=1,ns)
c --- pgb 11-21-84. change so can read 6 streamlines worth. top
read(15,*)(rfc(i),i=1,ns)
c -- pgb 11-21-84. change so can read 6 stream tubes worth. bottom
read(15,*)(st(i),i=1,ns)
read(15,*)(sm(i),i=1,ns)
read(15,*)(sh(i),i=1,ns)
read(15,*)(sfc(i),i=1,ns)
c -- pgb 11-21-84. change so can read in 6 stream lines worth. bottom
read(15,*)(block(i),i=1,ns)
read(15,*)(blocks(i),i=1,ns1)
read(15,*)idesin,idespt,jcent
c -- pgb 11-21-84. change so can read in 6 stream lines worth. top
do1152i=1,3
read(15,*)(bt1mra(i,j),j=1,ns)
1152 continue
do1153i=1,3
read(15,*)(bt2mra(i,j),j=1,ns)
1153 continue
do1154i=1,3
read(15,*)(bt1msa(i,j),j=1,ns1)
1154 continue
do1155i=1,3
read(15,*)(bt2msa(i,j),j=1,ns1)
1155 continue
read(15,*)dsmass,bypass
do57i=1,3
read(15,*)(pr12da(i,j),j=1,ns)
57 continue
do58i=1,3
read(15,*)(pr13da(i,j),j=1,ns)
58 continue
do59i=1,3
read(15,*)(etarda(i,j),j=1,ns)
59 continue
do60i=1,3
read(15,*)(xsarea(i,j),j=1,ns)
60 continue

```

```

do61i=1,3
read(15,*)(xareas(i,j),j=1,ns1)
61 continue
c -----
c nhg      the variable vairwa refers to the ratio of
c      the velocity of air to the velocity of some other phase
c      such as droplet (large or small) or film. the phase
c      with the smallest velocity should be used because, vairwa
c      is used to calculate residence time for centrifugal
c      calculations.
c ****
c      read(15,*)vairwa
c ****
c
c nhg      the variable clear(i) refers to the clearance
c      of the rotor.
c ****
c      read(15,*)(clear(i),i=1,ns)
c      read(15,*)(zdis(i),i=1,ns)
c      do 1523 i=1,ns
c          zdis(i) = zdis(i)/12.0
1523 continue
c ****
c * nhg      the variable jrad is being used because the
c *      variable irad is always set to a value of 2.. jrad
c *      represents the the stream line where the calculations
c *      are being done :
c *
c           1 = tip
c           2 = mean
c           3 = hub
c ****
c      read(15,*)jrad
5557 continue
c ajm
read(15,*)predes,temdes
c ****
c * changed program to read different values of the constants   *
c * ak1, ak2 and ak3 for each stage of the compressor.-skm.   *
c * nhg changed format from f5.3 to f6.4   ****
read(15,*)(ak1(i), i=1,ns)
read(15,*)(ak2(i), i=1,ns)
read(15,*)(ak3(i), i=1,ns)
c *+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
c the variables dvz1, dvz2, and dvz3 are the axial
c velocity of the gaseous working fluid at rotor inlet,
c rotor outlet, and stator outlet, respectively, for the
c design case.
c
c *+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*
```

```

do 62 i=1,3
read(15,*)(dvz1(i,j),j=1,ns1)
62 continue
do 64 i=1,3
read(15,*)(dvz2(i,j),j=1,ns1)
64 continue
do 66 i=1,3
read(15,*)(dvz3(i,j),j=1,ns)
66 continue
c *+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+
c the variables arine, aroute, and asoute are the effective
c streamtube areas corresponding to the design point case
c for rotor inlet, rotor outlet, and stator outlet,
c respectively. currently, the program does not use these
c values; instead the streamtube areas are calculated in the
c design point case such that the correct axial velocity
c is obtained at design. approximate values may be used.
c if the axial velocity data is not available for a machine
c then to obtain correct overall performance at design, the
c effective streamtube areas may be used.
c
c *+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+*+
read(15,*)(arine(i),i=1,ns)
read(15,*)(aroute(i),i=1,ns)
read(15,*)(asoute(i),i=1,ns)
c...added for plotting by pgb 7/5/84 top....
call getnm(nvinam)
c...added for plotting by pgb 7/5/84 bottom...
return
end
c ++++++ subroutine datinp
c developed to generate data and storeaway automatically.
c
character viname(13,4)
common /cdat3/jperfm,rhog(3),rerup,rerlow,resup,reslow
&,preb,rrtip(20),srtip(20),aaa1,aaa2,aaa3,sarea(20),sareas(20)
&,p(3),tg(3),xa,xv(3),xch4,xw(3),xww(3),xwt(3),tw(3),tww(3)
&,omegs(20),omegr(20),gapr(20),gaps(20),tsg(3),psg(3)
&,rrhub(20) , rc(20) , rblade(20) , stager(20)
&,srhub(20) , sc(20) , sblade(20),stages(20)
&,sigumr(20) , bet1sr(20) , bet2sr(20) , aincsr(20) , adevsr(20)
&,sigums(20) , bet1ss(20) , bet2ss(20) , aincss(20) , adevsss(20)
&,utipg(20),utip(20),utipd(20),uou(20),umean(20),uhub(20),u(20),fai
&,area(20),areas(20),uu2(20),utip2(20),umean2(20),uhub2(20),iprint
&,icent,iicent,fmr1(20),fma2(20),idesin,faid
&,ns,nsf,nslpc,bypass,ns1,rt(20),rm(20),rh(20),st(20),sm(20),sh(20)
&,dsmass,aarea(20),aareas(20),pr12d(20),pr13d(20),etard(20)
&,dr(20),ds(20),deqr(20),deqs(20),block(20),blocks(20)
&,bet1mr(20),bet2mr(20),bet1ms(20),bet2ms(20),radi1(20),radi2(20)
&,fairin(20),faiout(20),etasg(20),psid(20),taud(20),sitadr(20)

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&,sitads(20),wwd(20),vvd(20)
c common /cdat2/ rfc(20),sfc(20),bt2ssa(6,20),bt1mra(6,20),bt2mra
&(6,20),bt1msa(6,20),bt2msa(6,20),stagra(6,20),stagsa(6,20),
&etarda(6,20),pr12da(6,20),pr13da(6,20),rca(6,20),sca(6,20),
&sigra(6,20),sigmsa(6,20),xsarea(6,20),xareas(6,20)
c common /cdat4/ dvz1(3,20),dvz2(3,20),dvz3(3,20),arout(20),asout
&(20),arin(20),arine(20),aroute(20),asoute(20),ws(3),wmass(3),
$vmass(3),rhoa(3),rhom(3),tb(3),delz(20),etaa(20),dave(20),tdew
$(3),ddave(40),wwmass(3),wtmass(3),tmass(3),gmass(3),xair(3),
$xmetan(3),xgas(3),ak1(20),ak2(20),ak3(20),zdis(20),clear(20),
$cstara(20),fmmass(3),xf(3),watrgn(20),vaprgn(20),rcase(20),xws
$(20),watrgx(20),uis(20),jflag(20),hhcs(20)
c write(*,*)"no.of fan stages='
read(*,*)nsf
write(*,*)"no.of low pressure compressor stages='
read(*,*)nslpc
write(*,*)"no.of high pressure compressor stages='
read(*,*)nshpc
ns=nsf+nslpc+nshpc
ns1=ns+1
write(*,*)" data may be given at mean radius or three radii[1,3]:'
read(*,*)nset
write(*,*)"geom.data is read first for inlet guide vane [IGV] '
write(*,*)"followed by data for all stages (stator/rotor)',
$' (separated by comma)'
write(*,*)"For IGV:no.of blades,Rhub[in],Rtip[in],block factor '
read(*,*)nblad,srhub(ns1),srtip(ns1),blocks(ns1)
sblade(ns1)=float(nblad)
if(nset.eq.3)goto 2
write(*,*)"For IGV:mid-chord[in],mid_metal_angle[deg](entry,',
$'exit),solidity'
write(*,*)" abs. outlet flow angle [deg],stager_angle: '
read(*,*)sc(ns1),bet1ms(ns1),bet2ms(ns1),sigums(ns1),bet2ss(ns1)
$,stages(ns1)
do1i=1,3
sca(i,ns1)=sc(ns1)
bt1msa(i,ns1)=bet1ms(ns1)
bt2msa(i,ns1)=bet2ms(ns1)
bt2ssa(i,ns1)=bet2ss(ns1)
stagsa(i,ns1)=stages(ns1)
1 sigmsa(i,ns1)=sigums(ns1)
goto4
2 continue
do3i=1,3
write(*,*)"For IGV,set ',i,:chord[in],metal_angle[deg](entry,',
$'exit),solidity'
write(*,*)" abs_outlet_flow_angle [deg],stager_angle: '
3 read(*,*)sca(i,ns1),bt1msa(i,ns1),bt2msa(i,ns1),sigmsa(i,ns1),

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$bt2ssa(i,ns1),stagsa(i,ns1)
4  continue
do30ist=1,ns
write(*,*)' Stage',ist,' rotor:no.of blades,Rhub[in],Rtip[in],bl'
$',blockage factor,gapS_R[in]:'
read(*,*)nblad,rthub(ist),rrtip(ist),block(ist),gapr(ist)
rblade(ist)=float(nblad)
if(nset.eq.3)goto16
write(*,*)' Stage',ist,' rotor:chord[in],stager angle[deg],solidi'
*,ty,
write(*,*)'metal entry angle[deg],metal exit angle[deg]:'
read(*,*)rc(ist),stager(ist),sigumr(ist),bet1mr(ist),
$bet2mr(ist)
do15i=1,3
rca(i,ist)=rc(ist)
stagra(i,ist)=stager(ist)
sigmra(i,ist)=sigumr(ist)
bt1mra(i,ist)=bet1mr(ist)
bt2mra(i,ist)=bet2mr(ist)
15  continue
goto19
16  do17i=1,3
write(*,*)' For rotor stage ',ist,' set ',i
write(*,*)'chord[in],stager angle[deg],solidity,metal entry ',
$'angle[deg],exit angle[deg]'
read(*,*)rca(i,ist),stagra(i,ist),sigmra(i,ist),bt1mra(i,ist),
$bt2mra(i,ist)
17  continue
19  continue
write(*,*)' Stage',ist,' stator:no.of blades,Rhub[in],Rtip[in]',
$',blockage factor,gapR_S[in]:'
read(*,*)nblad,srhub(ist),srtip(ist),blocks(ist),gaps(ist)
sblade(ist)=float(nblad)
if(nset.eq.3)goto26
write(*,*)' Stage',ist,' stator:chord[in],stager angle[deg],'
*,'solidity'
write(*,*)'metal entry angle[deg],metal exit angle[deg],'
write(*,*)'absolute outlet flow angle[deg]:'
read(*,*)sc(ist),stages(ist),sigums(ist),bet1ms(ist),bet2ms
$(ist),bet2ss(ist)
do25i=1,3
sca(i,ist)=sc(ist)
stagsa(i,ist)=stages(ist)
sigmsa(i,ist)=sigums(ist)
bt1msa(i,ist)=bet1ms(ist)
bt2msa(i,ist)=bet2ms(ist)
bt2ssa(i,ist)=bet2ss(ist)
25  continue
goto30
26  do27i=1,3
write(*,*)' For stator stage ',ist,' set ',i

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write(*,*)'chord[in],stager angle[deg],solidity,metal entry angle'
$, '[deg],exit angle[deg],'
write(*,*)'absolute outlet flow angle [deg]: '
read(*,*)sca(i,ist),stagsa(i,ist),sigmsa(i,ist),bt1msa(i,ist),
$bt2msa(i,ist),bt2ssa(i,ist)
27 continue
30 continue
write(*,*)'Should rotor clearance be standard? '
read(*,31)rkey
31 format(a)
nclce=0
if(rkey.ne.'y'.and.rkey.ne.'Y')nclce=1
do50ist=1,ns
write(*,*)'For stage ',ist,' rotor: radii [in] - rt,rm,rh,rfc'
$', '(casing): '
read(*,*)rt(ist),rm(ist),rh(ist),rfc(ist)
write(*,*)'For stage ',ist,' stator: radii [in] - st,sm,sh,sfc'
$', '(casing): '
read(*,*)st(ist),sm(ist),sh(ist),sfc(ist)
50 continue
if(nclce.eq.0)goto52
write(*,*)'Rotor clearance [in] for ',ns,' rotors(sep.by comma):'
read(*,*)(clear(ist),ist=1,ns)
goto 55
52 continue
write(*,*)'rotor clearance[in]:'
write(*,*)'stage no. clearance[in]'
do53ist=1,ns
clear(ist)=(rt(ist)-rrhub(ist))*0.0025
if(clear(ist).lt.0.01)clear(ist)=0.01
write(*,*)ist,clear(ist)
53 continue
55 continue
write(*,*)'Axial stage length for ',ns,' stages(sep.by comma)',

$(zdis)[in]:'
read(*,*)(zdis(ist),ist=1,ns)
write(*,*)'Geometrical data completed'
write(*,*)'
write(*,*)'inlet flow coefficient(xphi)= '
read(*,*)xphi
write(*,*)'no.of steps per chord needed for centrifuging(ichord)'
read(*,*)ichord
write(*,*)'max.no.of sweeps(jend)= '
read(*,*)jend
write(*,*)'Wet case? '
read(*,31)rkey
nwater=1
if(rkey.eq.'Y'.or.rkey.eq.'y')nwater=2
irad=2
write(*,*)'jrad = 1/2/3 for tip/mean/hub: '
read(*,*)jrad

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write(*,*)'idesin = 1/2 for output stage+overall/overall: '
read(*,*)idesin
write(*,*)'idespt=0/1 for no_print/print of design point: '
read(*,*)idespt
write(*,58)
58 format('Design point data:',1x,'fan_rpm,inlet_stag_temp',
$'(R),inlet-stag-pressure(lb/sq.ft)',1x,'rpm_lpc,rpm_hpc'
$)
read(*,*)fnd,T01d,p01d,fndlpc,fndhpc
write(*,*)'standard day pressure(lbf/sq.ft),temp(oR):'
read(*,*)predes,temdes
write(*,*)'Overall mass flow rate (lbm/s), bypass ratio: '
read(*,*)Ovmass,bypass
dsmass=Ovmass*.1
59 format('For stage ',i2,'values for (p02/p01),(p03/p01),stage',
'$ efficiency')
do65ist=1,ns
if(nset.eq.3)goto62
write(*,59)ist
read(*,*)pr12d(ist),pr13d(ist),etard(ist)
do60i=1,3
pr12da(i,ist)=pr12d(ist)
pr13da(i,ist)=pr13d(ist)
60 etarda(i,ist)=etard(ist)
goto65
61 format('For stage ',i2,', set ',i1,', values for (p02/p01),(p03/',
1'p01),stage efficiency: ')
62 do63i=1,3
write(*,61)ist,i
read(*,*)pr12da(i,ist),pr13da(i,ist),etarda(i,ist)
63 continue
65 continue
69 format('For stage ',i2,', axial speeds (ft/s) at rotorin,rotor',
$'exit,statorexit')
do75ist=1,ns
if(nset.eq.3)goto72
write(*,69)ist
read(*,*)vrin,vrout,vsout
do70i=1,3
dvz1(i,ist)=vrin
dvz2(i,ist)=vrout
70 dvz3(i,ist)=vsout
goto75
71 format('For stage ',i2,', set ',i1,', axial speeds (ft/s) at',
1'rotorin,rotorexit,statorexit: ')
72 do73i=1,3
write(*,71)ist,i
read(*,*)dvz1(i,ist),dvz2(i,ist),dvz3(i,ist)
73 continue
75 continue
if(nset.eq.3)goto77

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write(*,*)'For IGV axial speeds (ft/s) at inlet and outlet:'
read(*,*)vrout,vsout
do76i=1,3
dvz1(i,ns1)=vrout
76 dvz2(i,ns1)=vsout
goto79
77 do78i=1,3
write(*,*)'For IGV, set ',i,' axial speeds (ft/s) at inlet and '
$',outlet'
78 read(*,*)dvz1(i,ns1),dvz2(i,ns1)
79 continue
write(*,*)'stream tube areas to be read ?'
read(*,31)rkey
if(rkey.eq.'Y'.or.rkey.eq.'y')goto90
dsm=dsmass/2.204623
nsf1=nsf+1
c 1 ft=0.3048 m; 1 sq.ft=0.092903 sq.m; 1 bar=2088.5 lbf/sq.ft
c 1 kg= 2.204623 lbm
do81i=1,3
T01K=T01d/1.8
p01bar=p01d/2088.5
do80ist=1,ns
if(ist.ne.nsf1)goto380
vzin=dvz1(i,ns1)*0.3048
TK=T01K-(vzin**2/2010.)
pbar=p01bar*(TK/T01K)**3.5
ro=pbar/(TK*0.002875)
xareas(i,ns1)=dsm/(ro*vzin*0.092903)
380 continue
vzin=dvz1(i,ist)*0.3048
TK=T01K-(vzin**2/2010.)
pbar=p01bar*(TK/T01K)**3.5
ro=pbar/(TK*0.002875)
xsarea(i,ist)=dsm/(ro*vzin*0.092903)
T02K=T01K*(1.+((pr12da(i,ist)**0.286-1.)/etarda(i,ist)))
p02bar=p01bar*pr12da(i,ist)
vzin=dvz2(i,ist)*0.3048
TK=T02K-(vzin**2/2010.)
pbar=p02bar*(TK/T02K)**3.5
ro=pbar/(TK*0.002875)
xareas(i,ist)=dsm/(ro*vzin*0.092903)
if(ist.eq.ns)goto80
T01K=T02K
p01bar=p01bar*pr13da(i,ist)
80 continue
81 continue
goto100
90 continue
if(nset.eq.3)goto95
91 format('rotor inlet stream tube area (sq.ft)(all stages): ')
write(*,91)

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```

read(*,*)(area(ist),ist=1,ns)
92  format('stator inlet stream tube area (sq.ft)(all stages + last '
$,'value for IGV')
write(*,92)
read(*,*)(areas(ist),ist=1,ns1)
do94i=1,3
do93ist=1,ns
93  xsarea(i,ist)=area(ist)
do94ist=1,ns1
xareas(i,ist)=areas(ist)
94  continue
goto100
95  continue
do96i=1,3
write(*,*)'For set ',i
write(*,91)
read(*,*)(xsarea(i,ist),ist=1,ns)
write(*,92)(xareas(i,ist),ist=1,ns1)
96  continue
100 continue
c  put approximate streamtube data in arine, aroute,asoute
do194ist=1,ns
arine(ist)=xsarea(2,ist)
aroute(ist)=xareas(2,ist)
if(ist.lt.ns)asoute(ist)=xsarea(2,ist+1)
if(ist.eq.ns)asoute(ist)=xareas(2,ist)
194 continue
write(*,*)'Off-design data'
write(*,*)'fraction of design corrected rotor speed for ',
$'off-design(1.0): '
read(*,*)fnf
fmwa=28.964
fmwv=18.016
fmch=16.043
xdin=0.
xddin=0.
din=20.
ddin=600.
rhumid=0.
icent=1
iicent=1
icentv=0
jcent=0
icase=0
T0w=597.
preb=1.
dlimit=10.
vairwa=80.
if(nwater.eq.1)goto110
write(*,*)'initial water percentage distribution cases - '
write(*,*)'2 for 2%, 4 for 4%, 5 for GE2, 7 for GE3: '

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```

read(*,*)icase
write(*,*)"jcent=0/1 for large droplets in rotor not _centr'
$',ifuged/centrif.'
read(*,*)jcent
101 format('cent,iicnet= 2, no restriction',/14x,
$'3, no heat and mass transfer',/14x,
$'4, no centrifugal action',/14x,'5, no heat/mass transfer',
$/centrifugal action',/14x,'6, no mass transfer',/14x,
$'7, no mass transfer/centrifugal action.',/icent,iicent =')
write(*,101)
read(*,*)icent,iicent
write(*,*)"initial mass content of small/large droplet(xdin'
$',xddin)= '
read(*,*)xdin,xddin
write(*,*)"initial small/large droplet dia(in micro-meter)',
$(din,ddin)= '
read(*,*)din,ddin
write(*,*)"initial water droplet temp. (in degr. R)= "
read(*,*)T0w
write(*,*)"initial water vapor content in air (kgv/kgair)",
$(rhumid)= '
read(*,*)rhumid
write(*,*)"percent of water that rebound from wall(preb)= "
read(*,*)preb
write(*,*)"max.dia (in micrometer) to be considered as small "
$',droplet(dlimit)= '
read(*,*)dlimit
write(*,*)"speed ratio air to condensed phase(vairwa)[%]= "
read(*,*)vairwa
write(*,*)"vapor is centrifuged?"
read(*,31)rkey
if(rkey.ne.'Y'.and.rkey.ne.'y')icentv=1
110 continue
write(*,*)"off design inlet temp(R),pressure(lbf/sq.ft)= "
read(*,*)T0g,p0
write(*,*)"Methane fraction= "
read(*,*)xch4
write(*,*)"ak1,ak2 and ak3 are 3 correction factors [1.]"
write(*,*)"use default values?<CR>"
read(*,31)rkey
ncor=0
if(rkey.eq.'N'.or.rkey.eq.'n')ncor=1
do411 ist=1,ns
if(ncor.eq.0) then
ak1(ist)=1.
ak2(ist)=1.
ak3(ist)=1.
endif
if(ncor.ne.0) then
write(*,*)"for stage',ist,' type ak1,ak2,ak3: "
read(*,*)ak1(ist),ak2(ist),ak3(ist)

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```

        endif
411  continue
      write(*,*)"input data being stored away -wait!"
157  format(4(i2,1x))
158  format(16(f5.2,1x))
159  format(16(f5.3,1x))
160  format(16(f7.5,1x))
161  format(16(f6.4,1x))
162  format(f7.1,2(1x,f7.2),2(1x,f7.1))
163  format(3(f6.3,1x))
      write(15,'(f4.2)')xphi
      write(15,157)ichord,jend,nwater,icase
      write(15,157)ns,nsf,nslpc,nshpc
      write(15,158)(rrhub(ist),ist=1,ns)
      do257i=1,3
      write(15,159)(rca(i,ist),ist=1,ns)
257  continue
      write(15,158)(rblade(ist),ist=1,ns)
      do258i=1,3
      write(15,158)(stagra(i,ist),ist=1,ns)
258  continue
      write(15,158)(srhub(ist),ist=1,ns1)
      do259i=1,3
      write(15,159)(sca(i,ist),ist=1,ns1)
259  continue
      write(15,158)(sblade(ist),ist=1,ns1)
      do260i=1,3
      write(15,158)(stagsa(i,ist),ist=1,ns1)
260  continue
      do261i=1,3
      write(15,159)(sigmra(i,ist),ist=1,ns)
261  continue
      do262i=1,3
      write(15,159)(sigmsa(i,ist),ist=1,ns1)
262  continue
      do263i=1,3
      write(15,158)(bt2ssa(i,ist),ist=1,ns1)
263  continue
      write(15,*)fnf
164  format(f5.3,1x,i1,1x,f5.3,1x,i1,1x,j1)
      write(15,*)xdin,icent,xddin,iicent,icentv
165  format(3(f7.2,1x))
      write(15,165)T0g,T0w,p0
166  format(2(f6.1,1x))
      write(15,166)din,ddin
      write(15,162)fnd,T01d,p01d,fndlpc,fndhpc
167  format(f5.3,1x,f10.5)
      write(15,167)xch4,rhumid
      write(15,163)fmwa,fmwv,fmch
168  format(f5.1,1x,f7.1)
      write(15,168)preb,dlimit

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write(15,160)(gapr(ist),ist=1,ns)
write(15,160)(gaps(ist),ist=1,ns)
write(15,159)(rrtip(ist),ist=1,ns)
write(15,159)(srtip(ist),ist=1,ns1)
write(15,*)irad
write(15,159)(rt(ist),ist=1,ns)
write(15,159)(rm(ist),ist=1,ns)
write(15,159)(rh(ist),ist=1,ns)
write(15,159)(rfc(ist),ist=1,ns)
write(15,159)(st(ist),ist=1,ns)
write(15,159)(sm(ist),ist=1,ns)
write(15,159)(sh(ist),ist=1,ns)
write(15,159)(sfc(ist),ist=1,ns)
write(15,159)(block(ist),ist=1,ns)
write(15,159)(blocks(ist),ist=1,ns1)
write(15,157)idesin,idespt,jcent
do264i=1,3
write(15,158)(bt1mra(i,ist),ist=1,ns)
264 continue
do265i=1,3
write(15,158)(bt2mra(i,ist),ist=1,ns)
265 continue
do266i=1,3
write(15,158)(bt1msa(i,ist),ist=1,ns1)
266 continue
do267i=1,3
write(15,158)(bt2msa(i,ist),ist=1,ns1)
267 continue
write(15,163)dsmass,bypass
do268i=1,3
write(15,159)(pr12da(i,ist),ist=1,ns)
268 continue
do269i=1,3
write(15,159)(pr13da(i,ist),ist=1,ns)
269 continue
do270i=1,3
write(15,159)(etarda(i,ist),ist=1,ns)
270 continue
170 format(8(f10.7,1x))
do271i=1,3
write(15,170)(xsarea(i,ist),ist=1,ns)
271 continue
do272i=1,3
write(15,170)(xareas(i,ist),ist=1,ns1)
272 continue
write(15,'(f6.2)')vairwa
write(15,161)(clear(ist),ist=1,ns)
write(15,159)(zdis(ist),ist=1,ns)
write(15,*)jrad
write(15,'(2f7.1)')predes,temdes
write(15,161)(ak1(ist),ist=1,ns)

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        write(15,161)(ak2(ist),ist=1,ns)
        write(15,161)(ak3(ist),ist=1,ns)
171   format(16(f5.1,1x))
        do1271i=1,3
        write(15,171)(dvz1(i,ist),ist=1,ns1)
1271   continue
        do1272i=1,3
        write(15,171)(dvz2(i,ist),ist=1,ns1)
1272   continue
        do273i=1,3
        write(15,171)(dvz3(i,ist),ist=1,ns)
273   continue
172   format(13(f6.4,1x))
        write(15,172)(arine(ist),ist=1,ns)
        write(15,172)(aroute(ist),ist=1,ns)
        write(15,172)(asoute(ist),ist=1,ns)
        write(*,*)"type upto twelve 4 byte words used by sub getnm"
        do275i=1,13
        read(*,'(4a1)')(viname(i,ist),ist=1,4)
        write(15,'(4a1)')(viname(i,ist),ist=1,4)
        if(viname(i,1).eq.'d'.and.viname(i,2).eq.'o')goto300
275   continue
300   continue
        write(*,*)"input data storage complete"
        return
        end
        subroutine htdgen
        character rkey
        character*20 filout,fildat
c   data generation interactively and storing away for later use
c   or to retrieve data from file for further calculation.
        common /htd1/filout,ndtop(20,8,6),ndmax(20),splen(20,8,4),
$arnod(20,8,4),htcap(20,8),casrad(20),excfc,expr(20),excfr
$(20,4),radex(20,4),tradd(145),xlcs(2,170),xro(2,170),rotdis(20)
$,dtimcl,rrv(145),cwork(300),rrvp(145),nexnod(4,20),
$nexcas(20),t0cas,tcas,rcas,ucas,trotor,rpm,rorot,urot,deltem
$,nboht,twcas,nemax,wfstrf,nrotcs,trchi(20),trcho(20),txw0(20),
$ttawm(20),tpawm(20),tvol(20),permax,txwc(20),ttawc(20),tpawc(20)
$,tmasa(20),dwat
c -----
c   meaning of variables in common block /htd1/ used here:
c   ndtop(i1,i2,i3), where i1=stage no.,i2=elem. no in stage,
c   i3=1:type no.,i3=2: no.of adj.nodes,i3>2:adj.node numbers)
c   ndmax=number of nodes in "ndtop" in each stage
c   splen=array for specific length ( $m^{**2} \cdot K/W$ ) for each node
c   arnod=array for interface surface area ( $m^{**2}$ )
c   htcap=heat capacity(J/K) for each nodal element
c   excfc=thermal expansion coefficient of casing material( $K^{**-1}$ )
c   expr=no.of nodes considered for thermal expansion of rotor in
c         each stage
c   excfr=thermal expansion coefficient for rotor nodes material ( $K^{**-1}$ )

```

```

c -----
c
write(*,*)' This subroutine helps for use in nodal temperature'
$, and clearance package '
write(*,*)' 1. to generate data, and'
write(*,*)' 2. to retrieve data for calculation.'
write(*,*)' --- choice: '
read(*,*)nchoic
if(nchoic.eq.1)write(*,*)' generated data to be stored in file: '
if(nchoic.eq.2)write(*,*)' data retrieval from file: '
1 format(a)
read(*,1)filout
open(17,file=filout)
goto(601,602),nchoic
write(*,*)'err STOP in sub htdgen'
Stop
601 continue
write(*,1602)
read(*,*)nrotcs
nelst=7
if(nrotcs.eq.3)nelst=8
write(*,*)'number of stages='
read(*,*)imax
write(*,*)'number of fan stages='
read(*,*)ifan
write(*,*)'max.number of elements per stage (',nelst,')='
read(*,*)jmax
write(*,*)'max.number of adj. nodes for each centroid node (4)='
read(*,*)kmax
if(imax.le.20.and.jmax.le.nelst.and.(kmax+2).le.6)goto5
write(*,*)'err stop in sub htdgen since array specified too ',
$'small'
close(17)
stop
5 continue
500 format(5(1x,i2))
1602 format(1x,'rotor internal cooling: ',/1x,'1. none: ',/1x,
$/2. cooled by air(with or without water) flow; and',
$/1x,'3. cooled by intermittently stagnant air-water mix.'
$/2x,' --- choice: ')
write(17,500)imax,ifan,jmax,kmax,nrotcs
c preparing nodal topology matrix
ic=0
do200i=1,imax
if(ic.ne.ifan)goto10
write(*,*)'nodal information for igv: 4 nodes'
jp=4
ndmax(ic+1)=jp
do4j=1,jp
write(*,*)'igv, for elem. ',j,', type no.(1-15):'
read(*,*)ntyp

```

```

nnd=4
if(ntyp.eq.1.or.ntyp.eq.4.or.ntyp.eq.5.or.ntyp.eq.7)nnd=3
if(ntyp.eq.6.or.ntyp.eq.15)nnd=2
if(ntyp.eq.8)nnd=1
ndtop(ic+1,j,1)=ntyp
ndtop(ic+1,j,2)=nnd
write(*,*)"heat capacity [J/K] for igv elem. ',j,:'
read(*,*)htcap(ic+1,j)
write(*,*)"node numbers for igv elem. ',j,',nnd,' adj.nodes:'
read(*,*)(ndtop(ic+1,j,k+2),k=1,nnd)
write(*,*)"Sij[m2] for igv elem. ',j,',nnd,' adj.nodes:'
read(*,*)(arnod(ic+1,j,k),k=1,nnd)
write(*,*)"ls[m2K/W] for igv elem. ',j,',nnd,' adj.nodes:'
read(*,*)(splen(ic+1,j,k),k=1,nnd)
write(17,501)ntyp,nnd,htcap(ic+1,j)
write(17,502)(ndtop(ic+1,j,k+2),k=1,nnd)
write(17,503)(arnod(ic+1,j,k),k=1,nnd)
write(17,503)(splen(ic+1,j,k),k=1,nnd)
501 format(2(1x,i3),10(1x,1pe11.4))
502 format(10(i3,1x))
503 format(10(1x,1pe11.4))
4 continue
ic=ic+1
10 continue
jp=nelst
write(*,*)"nodal information for stage ',i,' rotor',
$' followed by stator'
ndmax(ic+1)=jp
write(17,500)jp
do14j=1,jp
write(*,*)"for elem. ',j,' type no.(1-16):"
read(*,*)ntyp
nnd=4
if(ntyp.eq.1.or.ntyp.eq.4.or.ntyp.eq.5.or.ntyp.eq.7.or.
$ntyp.eq.16)nnd=3
if(ntyp.eq.8)nnd=1
if(ntyp.eq.6.or.ntyp.eq.15)nnd=2
ndtop(ic+1,j,1)=ntyp
ndtop(ic+1,j,2)=nnd
write(*,*)"heat capacity [J/K] for elem. ',j,:'
read(*,*)htcap(ic+1,j)
write(*,*)"node numbers for elem. ',j,',nnd,' adj.nodes:'
read(*,*)(ndtop(ic+1,j,k+2),k=1,nnd)
write(*,*)"Sij[m2] for elem. ',j,',nnd,' adj.nodes:'
read(*,*)(arnod(ic+1,j,k),k=1,nnd)
write(*,*)"ls[m2K/W] for elem. ',j,',nnd,' adj.nodes:'
read(*,*)(splen(ic+1,j,k),k=1,nnd)
write(17,501)ntyp,nnd,htcap(ic+1,j)
write(17,502)(ndtop(ic+1,j,k+2),k=1,nnd)
write(17,503)(arnod(ic+1,j,k),k=1,nnd)
write(17,503)(splen(ic+1,j,k),k=1,nnd)

```

```

14 continue
  ic=ic+1
200 continue
  write(*,*)'nodal information for 1 post node with 4 adj.nodes:'
  nnd=4
  ntyp=12
  ndmax(ic+1)=1
  ndtop(ic+1,1,1)=12
  ndtop(ic+1,1,2)=4
  write(*,*)'heat capacity [J/K] for post node:'
  read(*,*)htcap(ic+1,1)
  write(*,*)'node numbers for ',nnd,' adj.nodes of post node:'
  read(*,*)(ndtop(ic+1,1,k+2),k=1,nnd)
  write(*,*)'Sij[m2] for ',nnd,' adj.nodes of post node:'
  read(*,*)(arnod(ic+1,1,k),k=1,nnd)
  write(*,*)'ls[m2K/W] for ',nnd,' adj.nodes of post node:'
  read(*,*)(splen(ic+1,1,k),k=1,nnd)
  write(17,501)ntyp,nnd,htcap(ic+1,1)
  write(17,502)(ndtop(ic+1,1,k+2),k=1,nnd)
  write(17,503)(arnod(ic+1,1,k),k=1,nnd)
  write(17,503)(splen(ic+1,1,k),k=1,nnd)
  nnd=(imax*nelst)+5
  write(*,*)'no.of elements = ',nnd
  write(*,*)' axial coord.[in] for all elem.(put 0.,if irrelevant)'
  do201i=1,nnd
    write(*,*)'For elem. ',i,' case[in](upstr.),case(dnstr.):'
    read(*,*)xlcso(1,i),xlcso(2,i)
    write(17,202)xlcso(1,i),xlcso(2,i)
    write(*,*)'For elem. ',i,' rotor[in](upstr.),rotor(dnstr.):'
    read(*,*)xlro(1,i),xlro(2,i)
    write(17,202)xlro(1,i),xlro(2,i)
201 continue
202 format(2(1pe11.4,1x))
c
  write(*,*)'thermal expansion data'
  write(*,*)'coeff.of thermal exp.for casing(1/K): '
  read(*,*)excfcs
  write(17,*)excfcs
  do20i=1,imax
    write(*,*)'rotor stage no.= ',i
    write(*,*)
    $'casing thermal node no.,casing radius,rotor disk intern.radius'
    $',[in]='
    read(*,*)nexcas(i),casrad(i),rotdis(i)
    write(*,*)'no.of thermal expansion nodes in rotor stage ',i
    read(*,*)ntex
    nexpr(i)=ntex
    if(ntex.le.4)goto 11
    write(*,*)'err stop since size array excfr(,) insuff.'
    stop
11 continue

```

```

write(*,*)"thermal expansion nodes (',ntex,') in stage',i
read(*,*)(nexnod(itex,i),itex=1,ntex)
write(*,*)"coeff.of thermal expansion of ',ntex,' nodes in'
$, ' stage ',i,:'
read(*,*)(excfr(i,k),k=1,ntex)
write(*,*)"thermal expansion node length of ',ntex,' nodes in'
$, ' stage ',i,:'
read(*,*)(radex(i,k),k=1,ntex)
write(17,*)ntex,nexcas(i),casrad(i),rotdis(i)
write(17,504)(nexnod(itex,i),itex=1,ntex)
write(17,503)(excfr(i,k),k=1,ntex)
write(17,503)(radex(i,k),k=1,ntex)

20 continue
if(nrotcs.gt.1) then
write(*,*)'
write(*,*)" rotor disk is cooled by fluid flowing in channel'
write(*,*)" Data required for each cooled rotor disk are: '
write(*,*)" cooling channel min. and max. radius[in],'
write(*,*)" total volume of the cooling channel fluid[m**3],'
write(*,*)" cooling channel water content,temp.and pressure'
write(*,*)'
do21i=1,imax
write(*,*)
$'for stage ',i,':Ri[in],Ro[in],vol[m**3],xw,T[K],p[bar]'
read(*,*)trchi(i),trcho(i),tvol(i),txw0(i),ttawm(i),tpawm(i)
write(17,22)trchi(i),trcho(i),tvol(i),txw0(i),ttawm(i),tpawm(i)

21 continue
write(*,*)"water film thick. in rotor bore if water present[m]:'
read(*,*)dwat
write(17,*)dwat

22 format(1p6e12.5)
endif
if(nrotcs.eq.3) then
write(*,*)
$'cooling channel pressure incr. in percent of max.incr.possible'
read(*,*)permax
write(17,*)permax
endif

504 format(20(i2,1x))
close(17)
goto 603

602 continue
read(17,*)imax,ifan,jmax,kmax,nrotcs
nelst=7
if(nrotcs.eq.3)nelst=8
ic=0
do250i=1,imax
if(ic.ne.ifan)goto240
ndmax(ic+1)=4
do235j=1,4
read(17,*)ntyp,nnd,htcap(ic+1,j)

```

```

ndtop(ic+1,j,1)=ntyp
ndtop(ic+1,j,2)=nnd
read(17,*)(ndtop(ic+1,j,k+2),k=1,nnd)
read(17,*)(arnod(ic+1,j,k),k=1,nnd)
read(17,*)(splen(ic+1,j,k),k=1,nnd)
235 continue
ic=ic+1
240 continue
read(17,*)jp
ndmax(ic+1)=jp
do245j=1,jp
read(17,*)ntyp,nnd,htcap(ic+1,j)
ndtop(ic+1,j,1)=ntyp
ndtop(ic+1,j,2)=nnd
read(17,*)(ndtop(ic+1,j,k+2),k=1,nnd)
read(17,*)(arnod(ic+1,j,k),k=1,nnd)
read(17,*)(splen(ic+1,j,k),k=1,nnd)
245 continue
ic=ic+1
250 continue
ndmax(ic+1)=1
read(17,*)ntyp,nnd,htcap(ic+1,1)
ndtop(ic+1,1,1)=ntyp
ndtop(ic+1,1,2)=nnd
read(17,*)(ndtop(ic+1,1,k+2),k=1,nnd)
read(17,*)(arnod(ic+1,1,k),k=1,nnd)
read(17,*)(splen(ic+1,1,k),k=1,nnd)
nnd=(imax*nelst)+5
do252i=1,nnd
read(17,*)xlcs(1,i),xlcs(2,i)
read(17,*)xlro(1,i),xlro(2,i)
252 continue
read(17,*)excfcs
do260i=1,imax
read(17,*)ntex,nexcas(i),casrad(i),rotdis(i)
nexpr(i)=ntex
read(17,*)(nexnod(itex,i),itex=1,ntex)
read(17,*)(excf(i,k),k=1,ntex)
read(17,*)(radex(i,k),k=1,ntex)
260 continue
if(nrotcs.gt.1) then
do421i=1,imax
read(17,*)trchi(i),trcho(i),tvol(i),txw0(i),ttawm(i),tpawm(i)
421 continue
read(17,*)dwat
endif
if(nrotcs.eq.3)read(17,*)permax
close(17)
603 continue
write(*,*)"Nodal temp.and clearance output file: "
read(*,1)fildat

```

```

open(21,file=fildat)
604 format(1x,'Type in the following data:',/1x,'casing air'
$,'density(kg/m**3);',/1x,'casing air temp.(K);',/1x
$,'air speed outside casing(m/s);',/1x,'stagn.temp. of air'
$,'outside casing(K);',/1x,'airflow temp.inside rotor(K);',/
$,,1x,'airflow density inside rotor(K);',/1x,'airflow speed'
$,' inside rotor(m/s);',/1x,'delta_temp.(K) needed to'
$,'compute Grashof number in rotor disk(20.); and',/1x,
$,'water film surface temp.relax.factor(0. to 1.)',/)
write(*,604)
read(*,*)rucas,tcas,ucas,t0cas,trotor,rorot,urot,deltem
$,wfstrf
twcas=0.
write(*,*)'water film outside casing?'
read(*,1)rkey
if(rkey.eq.'Y'.or.rkey.eq.'y') then
write(*,*)'temp.of water film outside casing(K):'
read(*,*)twcas
endif
c write(*,*)'Output file for nodal temp. and clearance:'
c read(*,1)filout
c open(21,file=filout)
nemax=600
return
end
subroutine htexin
c reading of heat transfer data without asking
character*20 filin
common /htd1/filin,ndtop(20,8,6),ndmax(20),splen(20,8,4),
$arnod(20,8,4),htcap(20,8),casrad(20),excfcs,nexpr(20),excfcr
$(20,4),radex(20,4),tradd(145),xlcs(2,170),xlro(2,170),rotdis(20)
$,dtimcl,rrv(145),cwork(300),rrvp(145),nexnod(4,20),
$nexcas(20),t0cas,tcas,rucas,ucas,trotor,rpm,rorot,urot,deltem
$,nboht,twcas,nemax,wfstrf,nrotcs,trchi(20),trcho(20),txw0(20),
$ttawm(20),tpawm(20),tvol(20),permax,txwc(20),ttawc(20),tpawc(20)
$,tmasa(20),dwat
open(17,file=filin)
read(17,*)imax,ifan,jmax,kmax,nrotcs
nelst=7
if(nrotcs.eq.3)nelst=8
ic=0
do250i=1,imax
if(ic.ne.ifan)goto240
ndmax(ic+1)=4
do235j=1,4
read(17,*)ntyp,nnd,htcap(ic+1,j)
read(17,*)(ndtop(ic+1,j,k+2),k=1,nnd)
read(17,*)(arnod(ic+1,j,k),k=1,nnd)
read(17,*)(splen(ic+1,j,k),k=1,nnd)
235 continue
ic=ic+1

```

```

240 continue
  read(17,*)jp
  ndmax(ic+1)=jp
  do245j=1,jp
    read(17,*)ntyp,nnd,htcap(ic+1,j)
    read(17,*)(ndtop(ic+1,j,k+2),k=1,nnd)
    read(17,*)(arnod(ic+1,j,k),k=1,nnd)
    read(17,*)(splen(ic+1,j,k),k=1,nnd)
245 continue
  ic=ic+1
250 continue
  ndmax(ic+1)=1
  read(17,*)ntyp,nnd,htcap(ic+1,j)
  read(17,*)(ndtop(ic+1,j,k+2),k=1,nnd)
  read(17,*)(arnod(ic+1,j,k),k=1,nnd)
  read(17,*)(splen(ic+1,j,k),k=1,nnd)
  nnd=(imax*nelst)+5
  do252i=1,nnd
    read(17,*)xlcs(1,i),xlcs(2,i)
    read(17,*)xlro(1,i),xlro(2,i)
252 continue
  read(17,*)excfcs
  do260i=1,imax
    read(17,*)ntex,nexcas(i),casrad(i),rotdis(i)
    nexpr(i)=ntex
    read(17,*)(nexnod(itex,i),itex=1,ntex)
    read(17,*)(excf(i,k),k=1,ntex)
    read(17,*)(radex(i,k),k=1,ntex)
260 continue
  if(nrotcs.gt.1) then
    do21i=1,imax
      read(17,*)trchi(i),trcho(i),tvol(i),txw0(i),ttawm(i),tpawm(i)
21 continue
  read(17,*)dwat
  endif
  if(nrotcs.eq.3)read(17,*)permax
  close(17)
  return
  end
  function therex(istage)
c  calculation of rotor-casing clearance due to clearance gap
c -----
  common /htd1/ndum(5),ndtop(20,8,6),ndmax(20),splen(20,8,4),
$arnod(20,8,4),htcap(20,8),casrad(20),excfcs,nexpr(20),excf
$(20,4),radex(20,4),tradd(145),xlcs(2,170),xlro(2,170),rotdis(20)
$,dtimcl,rrv(145),cwork(300),rrvp(145),nexnod(4,20),
$nexcas(20),t0cas,tcas,rcas,ucas,trtor,rpm,rorot,urot,deltem
$,nboht,twcas,nemax,wfstrf,nrotcs,trchi(20),trcho(20),txw0(20),
$ttawm(20),tpawm(20),tvol(20),permax,txwc(20),ttawc(20),tpawc(20)
$,tmasa(20),dwat
c  meaning of variables in common block /htd1/:

```

```

c casrad=corresponding casing internal radius(not read in this
c subroutine)
c excfcs=thermal expansion coefficient of casing material(K**-1)
c nexpr=no.of nodes considered for thermal expansion of rotor in
c each stage
c ndexp=nodal array for thermal expansion of rotor
c excfr=thermal expansion coefficient for rotor nodes material (K**-1)
c radex=corresponding original radial length(not read in this subroutine)
c tradd(145)=temp.diff.(from orig.temp)(K) at all thermal nodes (input)
c -----
c
ndcas=nexcas(istage)
tdiff=tradd(ndcas)
casr=casrad(istage)*(1.+(excfcs*tdiff))
ndd=nexpr(istage)
rotl=0.
do10i=1,ndd
nod=nexnod(i,istage)
rotl=rotl+(radex(istage,i)*(1.+(excfr(istage,i)*tradd(nod))))
10 continue
therex=casr-rotl
100 format(a)
return
end
subroutine spear(nemax,i,j,n,lcur,lmax,inl,x,vl,iflag,ier)
c -----
c subroutine to extract/add/remove/replace in a sparse matrix(vers 8/93)
c nemax=max.length of 1-D array of inl(nemax),vl(nemax)
c i,j,n = (row,col.,order) of matrix
c index value manipulated in inl = ((i-1)*n)+j and correspond.value in vl.
c lcur,lmax = current,maximum location of pointer (initiate with lcur=0)
c x = external value for manipulation in the subroutine
c iflag = 1 to 4 for extract/add/remove/replace
c ier = error code on exit from the subroutine
c     = 0 (no error)
c     = 1 iflag,i,j,n not compatible
c     = 2 value to extract/remove not available
c     = 3 no space available to add
c     = 4 miscellaneous error
c -----
dimension inl(nemax),vl(nemax)
ier=0
k=j+((i-1)*n)
if(iflag.eq.2.and.lcur.eq.0)goto26
if(iflag.ne.2.and.lcur.eq.0)ier=4
if(ier.eq.4)goto 100
if(lcur.gt.lmax)lcur=lmax
ier=0
if(iflag.gt.0.and.iflag.lt.5.and.i.gt.0.and.i.le.n.and.j.gt.0
$.and.j.le.n.and.lcur.ge.0.and.lcur.le.lmax)goto 2
ier=1

```

```

      goto100
2   continue
c   examine movement forward or backward
kd=k-inl(lcur)
nd=0
if(kd.ne.0)nd=kd/iabs(kd)
ni=0
lc=lcur
if(nd.eq.0)ni=-1
if(ni.lt.0)goto 11
if(nd.gt.0.and.lcur.eq.lmax.and.iflag.eq.2)goto26
c   ni=0,-1,+1 for out of range,exact,intermediate
li=lcur
lf=lmax
lc=lcur
if(nd.gt.0)goto3
li=1
lf=lcur
3   continue
do10lin=li,lf
if(((k-inl(lc))*nd).eq.0)ni=-1
if(((k-inl(lc))*nd).lt.0)ni=1
if(ni.ne.0)goto11
10  lc=lc+nd
11  continue
if(ni.ge.0.and.iflag.ne.2)ier=2
if(ier.ne.0)goto 100
lcur=lc
if(ni.eq.0.and.nd.gt.0.and.iflag.eq.2)goto28
if(ni.eq.0.and.nd.lt.0.and.iflag.eq.2)goto27
if(ni.lt.0.and.iflag.eq.4)then
vl(lc)=x
return
endif
if(iflag.eq.2.and.ni.ge.0.and.(lmax+1).gt.nemax)ier=3
if(ier.ne.0)goto100
if(iflag.eq.2.and.ni.lt.0)vl(lc)=vl(lc)+x
if(iflag.eq.1.and.ni.lt.0)x=vl(lc)
if(iflag.ne.3.and.ni.lt.0)return
if(iflag.eq.2)goto15
lmax=lmax-1
if(lmax.le.0)ier=4
if(ier.ne.0)goto100
ntk=0
if(lcur.gt.lmax)ntk=1
if(ntk.eq.0)goto13
x=vl(lcur)
lcur=lmax
return
13  x=vl(lc)
do12ia=lcur,lmax

```

```

      inl(ia)=inl(ia+1)
12    vl(ia)=vl(ia+1)
      return
15    lmax=lmax+1
      if(ni.eq.1.and.nd.lt.0)lc=lc+1
      ka=k
      xa=x
      do20ia=lc,lmax
      xb=vl(ia)
      vl(ia)=xa
      kb=inl(ia)
      inl(ia)=ka
      ka=kb
20    xa=xb
25    lcur=lmax
      return
27    lc=1
      goto 15
28    lcur=lmax
26    lcur=lcur+1
      lmax=lcur
      if(lmax.gt.nemax)ier=3
      if(ier.eq.3)goto100
      inl(lcur)=k
      vl(lcur)=x
      return
100   write(*,*)'err return from sub spear'
      return
      end
c -----
c subroutine spcrp(i,n,lmax,nemax,inl,l1,l2,ld,ni)
c subroutine to find pointers on inl(nemax) for initial data l1,
c final data l2, and diagonal element ld for a given row no., i
c on exit,ni=no.of data in the row
c if ld=0: no diagonal element, ni=0: no data for the row
c i=row no.sought,n=order of matrix,lmax=pointer for furthest
c pointer for data in inl(nemax)
c dimension inl(nemax)
      l1=0
      l2=0
      ld=0
      ni=0
      k1=((i-1)*n)+1
      k2=k1+i-1
      k3=k1+n-1
      if(inl(1).gt.k3.or.inl(lmax).lt.k1)return
      do50l=1,lmax
      k=inl(l)
      if(k1.le.k.and.k.le.k3)goto 10
      goto 20
10    if(ni.eq.0)l1=l

```

```

ni=ni+1
if(k.eq.k2)ld=1
l2=l
goto 50
20 if(k.lt.k3)goto50
goto 60
50 continue
60 return
end
c -----
c subroutine spmsol(n,lmax,nemax,inl,vl,rv,c)
c subroutine for general sparse matrix solution
c n=order of matrix, lmax=max.value of pointer, nemax=size
c of two vectors inl(nemax) and vl(nemax), rv(n)=right
c hand side vector,c=working place
c
dimension vl(nemax),inl(nemax),rv(n),c(2,n),r(2)
ier=0
lcur=1
np=n-1
do1j=1,n
do1i=1,2
c(i,j)=0.
1 continue
do10i1=1,np
i=i1
call spcrp(i,n,lmax,nemax,inl,l11,l21,ld1,ni1)
if(ni1.eq.0)goto10
do2j=i1,n
2 c(1,j)=0.
do3i=l11,l21
k=inl(i)
j=k-((i1-1)*n)
if(j.lt.i1)goto 3
c(1,j)=vl(i)
3 continue
r(1)=rv(i1)
c addition of rows, if diagonal = 0
if(c(1,i1).ne.0.)goto36
l22=l21+1
do31i2=l22,lmax
k=inl(i2)
i=((k-1)/n)+1
j=k-((i-1)*n)
if(j.eq.i1.and.vl(i2).ne.0.)goto32
31 continue
lab=31
goto 20
32 call spcrp(i,n,lmax,nemax,inl,l12,l22,ld2,ni2)
lab=32
do33i2=l12,l22

```

```

k=inl(i2)
j=k-((i-1)*n)
if(j.lt.i1)goto 33
x=vl(i2)
k=i1
call spear(nemax,k,j,n,lcur,lmax,inl,x,vl,2,ier)
if(ier.ne.0) GOTO 20
33 continue
rv(i1)=rv(i1)+rv(i)
call spcrp(k,n,lmax,nemax,inl,l11,l21,ld1,ni1)
do34j=1,n
34 c(1,j)=0.
do35i=l11,l21
k=inl(i)
j=k-((i1-1)*n)
if(j.lt.i1)goto35
c(1,j)=vl(i)
35 continue
r(1)=rv(i1)
36 na=i1+1
do8i2=na,n
i=i2
call spcrp(i,n,lmax,nemax,inl,l12,l22,ld2,ni2)
if(ni2.eq.0)goto 8
do4j=i1,n
4 c(2,j)=0.
do5i=l12,l22
k=inl(i)
j=k-((i2-1)*n)
if(j.lt.i1)goto 5
c(2,j)=vl(i)
5 continue
r(2)=rv(i2)
xa=c(2,i1)/c(1,i1)
rv(i2)=r(2)-(r(1)*xa)
i=i2
lab=6
do6j1=i1,n
j=j1
x=0.
if(j.ne.i1)x=c(2,j)-(c(1,j)*xa)
nsp=0
if(c(2,j).eq.0..and.x.ne.0.)nsp=2
if(c(2,j).ne.0..and.x.eq.0.)nsp=3
if(c(2,j).ne.0..and.x.ne.0.)nsp=4
if(nsp.ne.0)call spear(nemax,i,j,n,lcur,lmax,inl,x,vl,nsp,ier)
if(ier.ne.0) goto 20
6 continue
8 continue
10 continue
k1=inl(1)

```

```

k2=inal(lmax)
i1=((k1-1)/n)+1
i2=((k2-1)/n)+1
if(((i1-1)*n)+i1).ne.k1.or.(((i2-1)*n)+i2).ne.k2)goto20
imin=n-i2+2
imax=n-i1+1
rv(i2)=rv(i2)/vl(lmax)
lab=15
do15is=imin,imax
i1=n-is+1
i=i1
call spcrp(i,n,lmax,nemax,inal,l11,l21,ld1,ni1)
if(ni1.eq.0)rv(i1)=0.
if(ni1.eq.0)goto15
if(ld1.eq.0)goto20
if(ld1.ne.0) then
  if(vl(ld1).eq.0.)goto20
endif
l12=ld1+1
if(i1.eq.n)goto14
do12j=l12,l21
k1=inal(j)
j1=k1-((i1-1)*n)
12  rv(i1)=rv(i1)-(vl(j)*rv(j1))
14  rv(i1)=rv(i1)/vl(ld1)
15  continue
return
20  write(*,*)'err stop in sub spmsol at label= ',lab
stop
end
subroutine stcoef
c   character rkey
c   computing coefficients for steady solution of heat conduction
c -----
c   ns=number of stages, nsf=number of fan stages
c
common /htd1/ndum(5),ndtop(20,8,6),ndmax(20),splen(20,8,4),
$arnod(20,8,4),htcap(20,8),casrad(20),excfc,expr(20),excfr
$(20,4),radex(20,4),tradd(145),xlcs(2,170),xlr(2,170),rotdis(20)
$,dtimcl,rrv(145),cwork(300),rrvp(145),nexnod(4,20),
$nexcas(20),t0cas,tcas,rcas,ucas,trotor,rpm,rorot,urot,deltem
$,nboht,twcas,nemax,wfstrf,nrotcs,trchi(20),trcho(20),txw0(20),
$ttawm(20),tpawm(20),tvol(20),permax,txwc(20),ttawc(20),tpawc(20)
$,tmasa(20),dwat
c   xlcs=(begin,end) coordinates [in] in axial direction
c           outside/inside casing for specified nodes
c   xlr=(begin,end) coordinates [in] in axial direction
c           at outer/inner rotor radius for specified nodes
c   t0cas[K],tcas[K],rcas[kg/m3],ucas[m/s] are gas-states outside
c   casing
c

```

```

common /hdat/tt1c(20),tt2c(20),tt3c(20),tro1c(20),tro2c(20),
$tro3c(20),tcm1c(20),tcm2c(20),tcm3c(20),tw1c(20),tw2c(20),tc1c
$(20),tc2c(20),tc3c(20),inl(600),vl(600),twcasr(20),twbr(20),
$twbs(20),trpmc(20)
c
common /cdat3/jperfm,rhog(3),rerup,rerlow,resup,reslow
&,preb,rrtip(20),srtip(20),aaa1,aaa2,aaa3,sarea(20),sareas(20)
&,p(3),tg(3),xa,xv(3),xch4,xw(3),xww(3),xwt(3),tw(3),tww(3)
&,omegs(20),omegr(20),gapr(20),gaps(20),tsg(3),psg(3)
&,rrhub(20) , rc(20) , rblade(20) , stager(20)
&,srhub(20) , sc(20) , sblade(20),stages(20)
&,sigumr(20) , bet1sr(20) , bet2sr(20) , aincsr(20) , adevsr(20)
&,sigums(20) , bet1ss(20) , bet2ss(20) , aincss(20) , adevss(20)
&,utipg(20),utip(20),utipd(20),uou(20),umean(20),uhub(20),u(20),fai
&,area(20),areas(20),uu2(20),utip2(20),umean2(20),uhub2(20),iprint
&,icent,iicent,fmr1(20),fma2(20),idesin,faid
&,ns,nsf,nslpc,bypass,ns1,rt(20),rm(20),rh(20),st(20),sm(20),sh(20)
&,dsmass,aarea(20),aareas(20),pr12d(20),pr13d(20),etard(20)
&,dr(20),ds(20),deqr(20),deqs(20),block(20),blocks(20)
&,bet1mr(20),bet2mr(20),bet1ms(20),bet2ms(20),radi1(20),radi2(20)
&,fairin(20),faiout(20),etasg(20),psid(20),taud(20),sitadr(20)
&,sitads(20),wwd(20),vvd(20)
c
c      dummy arrays
dimension nnv(4),vtmp(4)
real nu
ns1=ns+1
nele=(ns*7)+5
if(nrotcs.eq.3)nele=(ns*8)+5
c
pi=atan(1.)*4.
c
c      clear space in inl,vl,rrv
c
do1i=1,nemax
inl(i)=0
1   vl(i)=0.
do2i=1,nele
2   rrv(i)=0.
3   format(a)
c
c      calculate coefficient matrix, ipst=pointer on stages
c      ipel = pointer on element = pointer on row
jpc = pointer on column
c
ipst=1
ipel=1
lcur=0
lmax=0
do1000ist=1,ns
if((ipst-1).ne.nsf)goto100

```

c for IGV: nerow= no.of elements in IGV,nadj=no.of adjacent nodes
 nerow=ndmax(ipst)
 tblad=(tt2c(ns1)+tt3c(ns1)).5
 ub=(tc2c(ns1)+tc3c(ns1)).5
 rhob=(tro2c(ns1)+tro3c(ns1)).5
 do80i1=1,nerow
 do10i2=1,nadj
 vtmp(i2)=0.
 n3=ndtop(ipst,i1,i2+2)
 nnv(i2)=n3
 if(n3.gt.0.or.n3.eq.-74)vtmp(i2)=arnod(ipst,i1,i2)
 \$/splen(ipst,i1,i2)
 if(n3.eq.-72) then
 if(i1.eq.1.or.i1.eq.2) then
 if(i1.eq.1) then
 x1=xlro(1,i1)
 x2=xlro(2,i1)
 endif
 if(i1.eq.2) then
 x1=xlcso(1,i1)
 x2=xlcso(2,i1)
 endif
 x1=x1*0.0254
 x2=x2*0.0254
 tc=tt2c(ns1)
 xmu=1.8366e-5*(tc/300.)**.6
 ro=tro2c(ns1)
 uz=tcm2c(ns1)
 re1=ro*uz*x1/xmu
 re2=ro*uz*x2/xmu
 nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
 xl=abs(x2-x1)
 xk=xmu*1415.493
 vtmp(i2)=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
 endif
 if(i1.eq.4) then
 xl=sc(ns1)*.0254
 xmu=1.8366e-5*(tblad/300.)**0.6
 re=rhob*ub*xl/xmu
 nu=0.02063*re**0.8
 xk=xmu*1415.493
 vtmp(i2)=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
 endif
 endif
 if(n3.eq.-73) then
 x1=xlcso(1,i1)*0.0254
 x2=xlcso(2,i1)*0.0254
 xmu=1.8366e-5*(tcas/300.)**0.6
 xk=xmu*1415.493
 re1=rocas*ucas*x1/xmu

```

re2=rocas*ucas*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
vtmp(i2)=arnod(ipst,i1,i2)/((abs(x2-x1)/(nu*xk))+splen(ipst,i1
$,i2))
endif
if(n3.eq.-76) then
x1=xlro(1,i1)*.0254
x2=xlro(2,i1)*.0254
xmu=1.8366e-5*(totor/300.)**.6
re1=rrot*urot*x1/xmu
re2=rrot*urot*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
xl=abs(x2-x1)
xk=xmu*1415.493
vtmp(i2)=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
endif
c   write(*,*)'10:i1,i2,nadj,n3,vtmp(i2):',i1,i2,nadj,n3,vtmp(i2)
10  continue
sum=0.
do12i2=1,nadj
12  sum=sum+vtmp(i2)
do13i2=1,nadj
13  vtmp(i2)=vtmp(i2)/sum
call spear(nemax,ipel,ipel,nele,lcur,lmax,inl,-1.,vl,2,ier)
ichk=14
if(ier.ne.0)goto1005
do20i2=1,nadj
n3=nnv(i2)
if(n3.eq.-75)vtmp(i2)=0.
if(n3.lt.0.and.n3.ne.-75) then
if((i1.eq.2.or.i1.eq.3).and.(n3.eq.-73.or.n3.eq.-74)) then
tc=t0cas
rrv(ipel)=rrv(ipel)-(vtmp(i2)*tc)
vtmp(i2)=0.
endif
if(i1.eq.1) then
if(n3.eq.-74.or.n3.eq.-76)tc=totor
if(n3.eq.-72)tc=(tt2c(ns1)+tt2c(ns1))*.5
rrv(ipel)=rrv(ipel)-(vtmp(i2)*tc)
vtmp(i2)=0.
endif
if(i1.eq.2.and.n3.eq.-72) then
tc=tt2c(ns1)
rrv(ipel)=rrv(ipel)-(vtmp(i2)*tc)
vtmp(i2)=0.
endif
if(i1.eq.4.and.n3.eq.-72)then
tc=(tt2c(ns1)+tt2c(ns1))*.5
rrv(ipel)=rrv(ipel)-(vtmp(i2)*tc)
vtmp(i2)=0.
endif

```

```

endif
if(n3.gt.0.and.vtmp(i2).ne.0.) then
jpc=n3
val=vtmp(i2)
call spear(nemax,ipel,jpc,nele,lcu,lmax,inl,val,vl,2,ier)
ichk=20
if(ier.ne.0)goto1005
endif
20 continue
c  write(*,*)'20:ipel,ipst,nele,lmax:',ipel,ipst,nele,lmax
c  read(*,3)rkey
ipel=ipel+1
80 continue
ipst=ipst+1
100 continue
c  for stage nerow= no.of elements,nadj=no.of adjacent nodes
nerow=ndmax(ipst)
tbladr=(tt1c(ist)+tt2c(ist))* .5
ubr=(tw1c(ist)+tw2c(ist))* .5
ubmr=(tcm1c(ist)+tcm2c(ist))* .5
xmur=1.8366e-5*(tbladr/300.)**.6
xkr=xmur*1415.493
rhobr=(tro1c(ist)+tro2c(ist))* .5
tblads=(tt3c(ist)+tt2c(ist))* .5
ubs=(tc3c(ist)+tc2c(ist))* .5
ubms=(tcm3c(ist)+tcm2c(ist))* .5
xmus=1.8366e-5*(tblads/300.)**.6
xks=xmus*1415.493
rhobs=(tro2c(ist)+tro3c(ist))* .5
do180i1=1,nerow
nadj=ndtop(ipst,i1,2)
do110i2=1,nadj
vtmp(i2)=0.
n3=ndtop(ipst,i1,i2+2)
nnv(i2)=n3
if(n3.gt.0.or.n3.eq.-74)vtmp(i2)=arnod(ipst,i1,i2)
$/splen(ipst,i1,i2)
if(n3.eq.-71) then
if(i1.eq.1)xl=rc(ist)*0.0254
if(i1.eq.5)xl=abs(xlcso(2,ipel)-xlcso(1,ipel))*0.0254
re=rhobr*ubr*xl/xmur
nu=0.02063*re**0.8
vtmp(i2)=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
endif
if(n3.eq.-72) then
if(i1.eq.7)xl=sc(ist)*0.0254
if(i1.eq.4)xl=abs(xlro(2,ipel)-xlro(1,ipel))*0.0254
re=rhobs*ubs*xl/xmur
nu=0.02063*re**0.8
vtmp(i2)=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
endif

```

```

if(n3.eq.-73.and.i2.eq.3) then
x1=xlcso(1,ipel)*0.0254
x2=xlcso(2,ipel)*0.0254
xmu=1.8366e-5*(tcas/300.)*0.6
xk=xmu*1415.493
re1=rcas*ucas*x1/xmu
re2=rcas*ucas*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
vtmp(i2)=arnod(ipst,i1,i2)/((abs(x2-x1)/(nu*xk))+splen(ipst,i1,
$i2))
endif
if(n3.eq.-76) then
if(i1.eq.4) then
x1=xlro(1,ipel)*.0254
x2=xlro(2,ipel)*.0254
xmu=1.8366e-5*(trotor/300.)**.6
re1=rrotor*urot*x1/xmu
re2=rrotor*urot*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
xl=abs(x2-x1)
xk=xmu*1415.493
vtmp(i2)=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
endif
if(i1.eq.3) then
rroti=rotdis(ist)*.0254
omega=pi*rpm/30.
betdt=deltem/trotor
xmu=1.8366e-5*(trotor/300.)**.6
xk=xmu*1415.493
nu=0.0054*(rrotor*2.*urop*rroti/xmu)**0.3*((rrotor*omega/xmu)**2*
$betdt)**0.25
vtmp(i2)=arnod(ipst,i1,i2)/((1./(nu*xk))+splen(ipst,i1,i2))
endif
endif
if(n3.eq.-77) then
if(nrotcs.eq.2.or.(nrotcs.eq.3.and.i1.eq.3)) then
xwc=txw0(ist)
tc=tawm(ist)
trotin=tc
xvc=0.
pb=tpawm(ist)
rmc=(trchi(ist)+trcho(ist))*0.0127
xl=abs(trcho(ist)-trchi(ist))*0.0254
call mixprp(tc,pb,xvc,xwc,cpm,rhom,xnum,xkm,xkwat)
omega=pi*rpm/30.
gr=rmc*(omega*rhom/xnum)**2*deltem*xl**3/tc
pran=xnum*cpm/xkm
if(gr.le.1.e9)nu=0.508*(pran*gr/(pran+0.952))**0.25
if(gr.gt.1.e9)nu=0.024*(pran**1.17*gr/(1.+(pran**.666667*.494)
$))**.4
c if water present water thickness taken as 5 micron

```

```

dw=0.
if(xwc.gt.0.)dw=dwat
vtmp(i2)=
$arnod(ipst,i1,i2)/((xl/(xkm*nu))+(dw/xkwat)+splen(ipst,i1,i2))
vtmps=vtmp(i2)
endif
if(nrotcs.eq.3)vtmp(i2)=vtmps
endif
c   write(*,*)'110:i1,i2,nadj,n3,vtmp(i2):',i1,i2,nadj,n3,vtmp(i2)
110  continue
sum=0.
do112i2=1,nadj
112  sum=sum+vtmp(i2)
do113i2=1,nadj
113  vtmp(i2)=vtmp(i2)/sum
call spear(nemax,ipel,ipel,nele,lcur,lmax,inl,-1.,vl,2,ier)
ichk=114
if(ier.ne.0)goto1005
do120i2=1,nadj
n3=nnv(i2)
if(n3.eq.-75)vtmp(i2)=0.
if((n3.lt.0.and.n3.ne.-75.and.n3.ne.-77).or.(n3.eq.-77.and.
$nrotcs.eq.2)) then
if(n3.eq.-71)tc=(tt1c(ist)+tt2c(ist))*5
if(n3.eq.-72)tc=(tt2c(ist)+tt3c(ist))*5
if(i2.eq.3.and.(n3.eq.-73.or.n3.eq.-74))tc=t0cas
if(i2.eq.4.and.n3.eq.-74)tc=trotor
if(n3.eq.-76)tc=trotor
if(n3.eq.-77.and.nrotcs.eq.2)tc=trotin
rrv(ipel)=rrv(ipel)-(vtmp(i2)*tc)
vtmp(i2)=0.
endif
if((n3.gt.0.or.(n3.eq.-77.and.nrotcs.eq.3)).and.vtmp(i2).ne.0.)
$then
val=vtmp(i2)
jpc=n3
if(n3.eq.-77) then
if(i1.eq.3) jpc=((ist-1)*8)+12
if(i1.eq.8) jpc=((ist-1)*8)+7
endif
call spear(nemax,ipel,jpc,nele,lcur,lmax,inl,val,vl,2,ier)
ichk=120
if(ier.ne.0)goto1005
endif
120  continue
c   write(*,*)'120:ipel,ipst,nele,lmax:',ipel,ipst,nele,lmax
c   read(*,3)rkey
    ipel=ipel+1
180  continue
    ipst=ipst+1
1000 continue

```

```

c
c post-stage
c
nadj=ndtop(ipst,1,2)
do210i2=1,nadj
vtmp(i2)=0.
n3=ndtop(ipst,1,i2+2)
nnv(i2)=n3
if(n3.gt.0.or.n3.eq.-74)vtmp(i2)=arnod(ipst,1,i2)
$/splen(ipst,1,i2)
if(n3.eq.-72) then
xl=abs(xlcso(2,ipel)-xlcso(1,ipel))*0.0254
tc=tt3c(ns)
xmu=1.8366e-5*(tc/300.)**.6
xk=xmu*1415.493
re=tro3c(ns)*tcm3c(ns)*xl/xmu
nu=0.02063*re**0.8
vtmp(i2)=arnod(ipst,1,i2)/((xl/(nu*xk))+splen(ipst,1,i2))
endif
if(n3.eq.-73) then
x1=xlcso(1,ipel)*0.0254
x2=xlcso(2,ipel)*0.0254
xmu=1.8366e-5*(tcas/300.)**0.6
xk=xmu*1415.493
re1=rocas*ucas*x1/xmu
re2=rocas*ucas*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
vtmp(i2)=arnod(ipst,i1,i2)/((abs(x2-x1)/(nu*xk))+splen(ipst,i1,
$i2))
endif
c   write(*,*)'110:i1,i2,nadj,n3,vtmp(i2):',i1,i2,nadj,n3,vtmp(i2)
210  continue
sum=0.
do212i2=1,nadj
212  sum=sum+vtmp(i2)
do213i2=1,nadj
213  vtmp(i2)=vtmp(i2)/sum
call spear(nemax,ipel,ipel,nele,lcur,lmax,inl,-1.,vl,2,ier)
ichk=214
if(ier.ne.0)goto1005
do220i2=1,nadj
n3=nnv(i2)
if(n3.eq.-75)vtmp(i2)=0.
if(n3.lt.0.and.n3.ne.-75) then
if(n3.eq.-72)tc=(tt2c(ist)+tt3c(ist))*5
if(i2.eq.3.and.(n3.eq.-73.or.n3.eq.-74))tc=t0cas
rrv(ipel)=rrv(ipel)-(vtmp(i2)*tc)
vtmp(i2)=0.
endif
val=vtmp(i2)
if(n3.gt.0.and.val.ne.0.) then

```

```

jpc=n3
call spear(nemax,ipel,jpc,nele,lcur,lmax,inl,val,vl,2,ier)
ichk=220
if(ier.ne.0)goto1005
endif
220 continue
c   write(*,*)'220:ipel,ipst,nele,lmax:',ipel,ipst,nele,lmax
c   read(*,3)rkey
      if(lmax.ge.nemax) then
        write(*,*)"insufficient space in arrays inl(),vl()."
        write(*,*)"increase value of nemax, and array size of ",
        '$inl(),vl() to more than',lmax
        write(*,*)"recompile and run after correction"
        stop
      endif
c   solution of equations
call spmsol(nele,lmax,nemax,inl,vl,rrv,cwork)
if(nrotcs.gt.1) then
  rair=8314.3/28.964
  do230i1=1,ns
    txwc(i1)=txw0(i1)
    ttawc(i1)=ttawm(i1)
    tpawc(i1)=tpawm(i1)
    tmasa(i1)=tpawm(i1)*1.e5*tvol(i1)/(rair*ttawm(i1))
    if(nrotcs.eq.3)rrv(((i1-1)*8)+12)=ttawc(i1)
230 continue
  endif
  return
1005 write(*,*)
      '$err stop in sub stcoef, ichk,ier,lcur,lmax,nemax= ',
      '$ichk,ier,lcur,lmax,nemax'
      stop
end
subroutine tdcoef
c   character rkey
c   computing coefficients for steady solution of heat conduction
c -----
c   ns=number of stages, nsf=number of fan stages
c   nopt=1/2 for steady-state/time-dependent solution
c
c   common /htd1/ndum(5),ndtop(20,8,6),ndmax(20),splen(20,8,4),
c   $arnod(20,8,4),htcap(20,8),casrad(20),excfcs,nexpr(20),excfr
c   $(20,4),radex(20,4),tradd(145),xlcs(2,170),xlro(2,170),rotdis(20)
c   $,dtimcl,rrv(145),cwork(300),rrvp(145),nexnod(4,20),
c   $nexcas(20),t0cas,tcas,ucas,trotor,rpm,rorot,urot,deltem
c   $,nboht,twcas,nemax,wfstrf,nrotcs,trchi(20),trcho(20),txw0(20),
c   $ttawm(20),tpawm(20),tvol(20),permax,txwc(20),ttawc(20),tpawc(20)
c   $,tmasa(20),dwat
c   xlcs=(begin,end) coordinates [in] in axial direction
c           outside/inside casing for specified nodes
c   xlro=(begin,end) coordinates [in] in axial direction

```

```

c      at outer/inner rotor radius for specified nodes
c      t0cas[K],tcas[K],rcas[kg/m3],ucas[m/s] are gas-states outside
c      casing
c
c      common /hdat/tt1c(20),tt2c(20),tt3c(20),tro1c(20),tro2c(20),
c      $tro3c(20),tcm1c(20),tcm2c(20),tcm3c(20),tw1c(20),tw2c(20),tc1c
c      $(20),tc2c(20),tc3c(20),inl(600),vl(600),twcasr(20),twbr(20),
c      $twbs(20),trpmc(20)
c
c      common /cdat3/jperfm,rhog(3),rerup,rerlow,resup,reslow
c      &,preb,rrtip(20),srtip(20),aaa1,aaa2,aaa3,sarea(20),sareas(20)
c      &,p(3),tg(3),xa,xv(3),xch4,xw(3),xww(3),xwt(3),tw(3),tww(3)
c      &,omegs(20),omegr(20),gapr(20),gaps(20),tsg(3),psg(3)
c      &,rrhub(20) , rc(20) , rblade(20) , stager(20)
c      &,srhub(20) , sc(20) , sblade(20),stages(20)
c      &,sigumr(20) , bet1sr(20) , bet2sr(20) , aincsr(20) , adevsr(20)
c      &,sigums(20) , bet1ss(20) , bet2ss(20) , aincss(20) , adevss(20)
c      &,utipg(20),utip(20),utipd(20),uou(20),umean(20),uhub(20),u(20),fai
c      &,area(20),areas(20),uu2(20),utip2(20),umean2(20),uhub2(20),iprint
c      &,icent,iicent,fmr1(20),fma2(20),idesin,faid
c      &,ns,nsf,nslpc,bypass,ns1,rt(20),rm(20),rh(20),st(20),sm(20),sh(20)
c      &,dsmass,aarea(20),aareas(20),pr12d(20),pr13d(20),etard(20)
c      &,dr(20),ds(20),deqr(20),deqs(20),block(20),blocks(20)
c      &,bet1mr(20),bet2mr(20),bet1ms(20),bet2ms(20),radi1(20),radi2(20)
c      &,fairin(20),faiout(20),etasg(20),psid(20),taud(20),sitadr(20)
c      &,sitads(20),wwd(20),vvd(20)
c
c      dimension nnv(4),vtmp(4)
c      real nu
c
c      pi=atan(1.)*4.
c      ns1=ns+1
c      if(nrotcs.eq.3), compute heat capacity for 8th node in each stage.
c      if(nrotcs.eq.3) then
c          do401i=1,ns
c              xwc=txwc(i)
c              xvc=txw0(i)-txwc(i)
c              tc=ttawc(i)
c              pb=tpawc(i)
c              call mixprp(tc,pb,xvc,xwc,cpm,rhom,xmum,xkm,xkwat)
c              htcap(i+1,8)=rhom*tvol(i)*cpm
c          write(*,*)'tdc:i,rho,vol,cpm,Mc='i,rhom,tvol(i),cpm,htcap(i+1,8)
c        401  continue
c      read(*,3)rkey
c      endif
c3      format(a)
c
c      clear space in inl,vl; store away old data to rrwp
c
c      nele=(ns*7)+5
c      if(nrotcs.eq.3)nele=(ns*8)+5

```

```

do1i=1,nemax
inl(i)=0
1   vl(i)=0.
do2i=1,nele
rrvp(i)=rrv(i)
2   rrv(i)=0.
c
c calculate coefficient matrix, ipst=pointer on stages
c ipel = pointer on element = pointer on row
jpc = pointer on column
c
ipst=1
ipel=1
lcur=0
lmax=0
do1000ist=1,ns
if((ipst-1).ne.nsf)goto100
c for IGV: nerow= no.of elements in IGV,nadj=no.of adjacent nodes
dtime=dtimcl
nerow=ndmax(ipst)
tblad=(tt2c(ns1)+tt3c(ns1))*5
ub=(tc2c(ns1)+tc3c(ns1))*5
rhob=(tro2c(ns1)+tro3c(ns1))*5
do80i1=1,nerow
nadj=ndtop(ipst,i1,2)
htc=htcap(ipst,i1)
con=dtime*.5/htc
ajtj=0.
aktk=0.
aos=0.
do10i2=1,nadj
heff=0.
n3=ndtop(ipst,i1,i2+2)
nnv(i2)=n3
if(n3.gt.0.or.n3.eq.-74)heff=arnod(ipst,i1,i2)
$/splen(ipst,i1,i2)
if(n3.eq.-72) then
if(i1.eq.1.or.i1.eq.2) then
if(i1.eq.1) then
x1=xlro(1,i1)
x2=xlro(2,i1)
tc=tblad
endif
if(i1.eq.2) then
x1=xlcs(1,i1)
x2=xlcs(2,i1)
tc=tt2c(ns1)
endif
x1=x1*0.0254
x2=x2*0.0254
xmu=1.8366e-5*(tc/300.)**.6

```

```

ro=tro2c(ns1)
uz=tcm2c(ns1)
re1=ro*uz*x1/xmu
re2=ro*uz*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
xl=abs(x2-x1)
endif
if(i1.eq.4) then
xl=sc(ns1)*.0254
tc=tblad
xmu=1.8366e-5*(tblad/300.)**0.6
re=rhob*ub*xl/xmu
nu=0.02063*re**0.8
endif
xk=xmu*1415.493
heff=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
endif
if(n3.eq.-73) then
tc=t0cas
x1=xlcso(1,i1)*0.0254
x2=xlcso(2,i1)*0.0254
xmu=1.8366e-5*(tcas/300.)**0.6
xk=xmu*1415.493
re1=rcas*ucas*x1/xmu
re2=rcas*ucas*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
heff=arnod(ipst,i1,i2)/((abs(x2-x1)/(nu*xk))+splen(ipst,i1,
$i2))
endif
if(n3.eq.-76) then
tc=trotor
x1=xlro(1,i1)*.0254
x2=xlro(2,i1)*.0254
xmu=1.8366e-5*(trotor/300.)**.6
re1=rorot*urop*x1/xmu
re2=rorot*urop*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
xl=abs(x2-x1)
xk=xmu*1415.493
heff=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
endif
if(twcas.ne.0.) then
if(i2.eq.3.and.(i1.eq.2.or.i1.eq.3)) then
tout=t0cas
tnode=rrvp(ipel)
tsurfo=((tout-tnode)*heff*splen(ipst,i1,i2))+tnode
tsurf=(tsurfo*(1.-wfstrf))+(wfstrf*twcas)
hcor=(tsurf-tnode)/(splen(ipst,i1,i2)*(tout-tsurf))
heff=1./((1./abs(hcor))+splen(ipst,i1,i2))
endif
endif

```

```

twc=twbs(ns1)
if(twc.gt.0..and.i1.eq.4.and.i2.eq.2) then
tout=tblad
tnode=rrvp(ipel)
tsurfo=((tout-tnode)*heff*splen(ipst,i1,i2))+tnode
tsurf=(tsurfo*(1.-wfstrf))+(wfstrf*twc)
hcor=(tsurf-tnode)/(splen(ipst,i1,i2)*(tout-tsurf))
heff=1./((1./abs(hcor))+splen(ipst,i1,i2))
endif
vtmp(i2)=heff*con
c   write(*,*)'10:i1,i2,nadj,n3,vtmp(i2):',i1,i2,nadj,n3,vtmp(i2)
if(n3.eq.-74.and.i2.eq.3)tc=t0cas
if(n3.eq.-74.and.i2.eq.4)tc=trotor
if(n3.gt.0)ajtj=ajtj+(vtmp(i2)*rrvp(n3))
aos=aos+vtmp(i2)
if(n3.gt.0.or.n3.eq.-75)goto 10
aktk=aktk+(tc*vtmp(i2))
vtmp(i2)=0.
10  continue
c   aktk=sum(ak'*Tk); ajtj=sum(aj'*Tj), j.ne.(k.or.l)
do14i2=1,nadj
n3=nnv(i2)
13  if(n3.lt.0)goto 14
val=-vtmp(i2)
jpc=n3
call spear(nemax,ipel,jpc,nele,lcu,lmax,inl,val,vi,2,ier)
ichk=13
if(ier.ne.0)goto1005
14  continue
rrv(ipel)=(rrvp(ipel)*(1.-aos))+ajtj+(aktk*2.)
vc=1.+aos
call spear(nemax,ipel,ipel,nele,lcu,lmax,inl,vc,vi,2,ier)
ichk=14
if(ier.ne.0)goto1005
c   write(*,*)'80:ipel,ipst,nele,lmax:',ipel,ipst,nele,lmax
c   read(*,3)rkey
ipel=ipel+1
80  continue
ipst=ipst+1
100 continue
c   for stage nerow= no.of elements,nadj=no.of adjacent nodes
nerow=ndmax(ipst)
dtime=dtimcl
tbladr=(tt1c(ist)+tt2c(ist))*5
ubr=(tw1c(ist)+tw2c(ist))*5
ubmr=(tcm1c(ist)+tcm2c(ist))*5
xmur=1.8366e-5*(tbladr/300.)**.6
xkr=xmur*1415.493
rhobr=(tro1c(ist)+tro2c(ist))*5
tblads=(tt3c(ist)+tt2c(ist))*5
ubs=(tc3c(ist)+tc2c(ist))*5

```

```

ubms=(tcm3c(ist)+tcm2c(ist)).*.5
xmus=1.8366e-5*(tblads/300.)**.6
xks=xmus*1415.493
rhobs=(tro2c(ist)+tro3c(ist)).*.5
do180i1=1,nerow
if(i1.gt.4)dtime=dtimcl
nadj=ndtop(ipst,i1,2)
htc=htcap(ipst,i1)
con=dtime*.5/htc
aktk=0.
ajtj=0.
aos=0.
do110i2=1,nadj
heff=0.
n3=ndtop(ipst,i1,i2+2)
nnv(i2)=n3
if(n3.gt.0.or.n3.eq.-74)heff=arnod(ipst,i1,i2)
$/splen(ipst,i1,i2)
if(n3.eq.-71) then
if(i1.eq.1)xl=rc(ist)*0.0254
if(i1.eq.5)xl=abs(xlcso(2,ipel)-xlcso(1,ipel))*0.0254
re=rhobr*ubr*xl/xmur
nu=0.02063*re**0.8
heff=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
tc=tbladr
endif
if(n3.eq.-72) then
if(i1.eq.7)xl=sc(ist)*0.0254
if(i1.eq.4)xl=abs(xlro(2,ipel)-xlro(1,ipel))*0.0254
re=rhobs*ubs*xl/xmur
nu=0.02063*re**0.8
heff=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
tc=tblads
endif
if(n3.eq.-73.and.i2.eq.3) then
x1=xlcso(1,ipel)*0.0254
x2=xlcso(2,ipel)*0.0254
xmu=1.8366e-5*(tcas/300.)*0.6
xk=xmu*1415.493
re1=rocas*uclas*x1/xmu
re2=rocas*uclas*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
heff=arnod(ipst,i1,i2)/((abs(x2-x1)/(nu*xk))+splen(ipst,
$i1,i2))
tc=t0cas
endif
if(n3.eq.-76) then
tc=trotor
xmu=1.8366e-5*(trotor/300.)**.6
xk=xmu*1415.493
if(i1.eq.4) then

```

```

x1=xlro(1,ipel)*.0254
x2=xlro(2,ipel)*.0254
re1=rorot*urot*x1/xmu
re2=rorot*urot*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
xl=abs(x2-x1)
heff=arnod(ipst,i1,i2)/((xl/(nu*xk))+splen(ipst,i1,i2))
endif
if(i1.eq.3) then
rroti=rotdis(ist)*.0254
omega=pi*trpmc(ist)/30.
delt=deltem
do105il=1,10
betdt=abs(delt)/trotor
nu=0.0054*(rorot*2.*urot*rroti/xmu)**0.3*((rorot*omega/xmu)**2
$*betdt)**0.25
arn=arnod(ipst,i1,i2)
heff=arn/((1./(nu*xk))+splen(ipst,i1,i2))
deltn=abs((rrvp(ipel)-trotor)*(1.-(splen(ipst,i1,i2)*heff/arn)))
dell=deltn-delt
delt=deltn
if(abs(dell).lt.(abs(delt)*1.e-5))goto106
105 continue
106 continue
endif
endif
if(n3.eq.-77) then
if(nrotcs.eq.2.or.(nrotcs.eq.3.and.i1.eq.3)) then
xwc=txwc(ist)
tc=ttawc(ist)
trotin=tc
xvc=txw0(ist)-xwc
pb=tpawc(ist)
rmc=(trchi(ist)+trcho(ist))*0.0127
xl=abs(trcho(ist)-trchi(ist))*0.0254
call mixprp(tc,pb,xvc,xwc,cpm,rhom,xmum,xkm,xkwat)
omega=pi*trpmc(ist)/30.
pran=xmum*cpm/xkm
if(nrotcs.eq.3)tmet=rrvp(((ist-1)*8)+7)
if(nrotcs.eq.2)tmet=rrvp(((ist-1)*7)+7)
xls=splen(ipst,i1,i2)
arn=arnod(ipst,i1,i2)
c if water present water thickness taken as given
dw=0.
if(xwc.gt.0.)dw=dwat
delt=deltem
do107il=1,10
gr=rmc*(omega*rhom/xmum)**2*abs(delt)*xl**3/tc
if(gr.le.1.e9)nu=0.508*(pran*gr/(pran+0.952))**0.25
if(gr.gt.1.e9)nu=0.024*(pran**1.17*gr/(1.+(pran**.666667*.494)
$))**.4

```

```

heff=abs(arn/((xl/(xkm*nu))+(dw/xkwat)+xls))
deltn=abs(tc-tmet)*(1.-(heff*xls/arn))
dell=deltn-delt
delt=abs(delt)
if(abs(dell).lt.(abs(delt*1.e-5)))goto108
107 continue
108 continue
heffs=heff
endif
if(nrotcs.eq.3)heff=heffs
endif
if(twcas.ne.0) then
if(i2.eq.3.and.(i1.eq.5.or.i1.eq.6))then
tout=t0cas
tnode=rrvp(ipel)
tsurfo=((tout-tnode)*heff*splen(ipst,i1,i2))+tnode
tsurf=(tsurfo*(1.-wfstrf))+(wfstrf*twcas)
hcor=(tsurf-tnode)/(splen(ipst,i1,i2)*(tout-tsurf))
heff=1./((1./abs(hcor))+splen(ipst,i1,i2))
endif
endif
twc=twbr(ist)
if(twc.gt.0..and.(i1.eq.1.or.i1.eq.5)) then
if((i1.eq.1.and.i2.eq.2).or.(i1.eq.5.and.i2.eq.4)) then
tout=tbladr
tnode=rrvp(ipel)
tsurfo=((tout-tnode)*heff*splen(ipst,i1,i2))+tnode
tsurf=(tsurfo*(1.-wfstrf))+(wfstrf*twc)
hcor=(tsurf-tnode)/(splen(ipst,i1,i2)*(tout-tsurf))
heff=1./((1./abs(hcor))+splen(ipst,i1,i2))
endif
endif
twc=twbs(ist)
if(twc.gt.0..and.i1.eq.7.and.i2.eq.2) then
tout=tblads
tnode=rrvp(ipel)
tsurfo=((tout-tnode)*heff*splen(ipst,i1,i2))+tnode
tsurf=(tsurfo*(1.-wfstrf))+(wfstrf*twc)
hcor=(tsurf-tnode)/(splen(ipst,i1,i2)*(tout-tsurf))
heff=1./((1./abs(hcor))+splen(ipst,i1,i2))
endif
vtmp(i2)=heff*con
aos=aos+vtmp(i2)
if(n3.eq.-74.and.i2.eq.3)tc=t0cas
if(n3.eq.-74.and.i2.eq.4)tc=trotor
if(n3.gt.0)ajtj=ajtj+(vtmp(i2)*rrvp(n3))
if(n3.eq.-77.and.nrotcs.eq.3) then
if(i1.eq.3)jpc=((ist-1)*8)+12
if(i1.eq.8)jpc=((ist-1)*9)+7
ajtj=ajtj+(vtmp(i2)*rrvp(jpc))
endif

```

```

c   write(*,*)'110:i1,i2,nadj,n3,heff,con:',i1,i2,nadj,n3,heff,con
    if(n3.gt.0.or.n3.eq.-75.or.(n3.eq.-77.and.nrotcs.eq.3))goto 110
    aktk=aktk+(tc*vtmp(i2))
    vtmp(i2)=0.
110  continue
    do114 i2=1,nadj
        n3=nnv(i2)
113  if((n3.lt.-70.and.n3.gt.-77).or.(n3.eq.-77.and.nrotcs.eq.2))
    $goto 114
    val=-vtmp(i2)
    jpc=n3
    if(n3.eq.-77) then
        if(i1.eq.3)jpc=((ist-1)*8)+12
        if(i1.eq.8)jpc=((ist-1)*9)+7
        endif
        call spear(nemax,ipel,jpc,nele,lcu,lmax,inl,val,vl,2,ier)
        ichk=113
        if(ier.ne.0)goto 1005
114  continue
    rrv(ipel)=(rrvp(ipel)*(1.-aos))+ajtj+(aktk*2.)
    vc=1.+aos
    call spear(nemax,ipel,ipel,nele,lcu,lmax,inl,vc,vl,2,ier)
    ichk=114
    if(ier.ne.0)goto 1005
c   write(*,*)'120:ipel,ipst,nele,lmax:',ipel,ipst,nele,lmax
c   read(*,3)rkey
    ipel=ipel+1
180  continue
    ipst=ipst+1
1000 continue
c
c   post-stage
c
    dtime=dtimcl
    nadj=ndtop(ipst,1,2)
    htc=htcap(ipst,1)
    con=dtime*.5/htc
    aktk=0.
    ajtj=0.
    aos=0.
    i1=1
    do210 i2=1,nadj
        heff=0.
        n3=ndtop(ipst,1,i2+2)
        nnv(i2)=n3
        if(n3.gt.0.or.n3.eq.-74)heff=arnod(ipst,1,i2)
        $/splen(ipst,1,i2)
        if(n3.eq.-72) then
            xl=abs(xlcso(2,ipel)-xlcso(1,ipel))*0.0254
            tc=tt3c(ns)
            xmu=1.8366e-5*(tc/300.)**.6

```

```

xk=xmu*1415.493
re=tro3c(ns)*tcm3c(ns)*xl/xmu
nu=0.02063*re**0.8
heff=arnod(ipst,1,i2)/((xl/(nu*xk))+splen(ipst,1,i2))
endif
if(n3.eq.-73) then
x1=xlcso(1,ipel)*0.0254
x2=xlcso(2,ipel)*0.0254
xmu=1.8366e-5*(tcas/300.)**0.6
xk=xmu*1415.493
re1=rocas*ucas*x1/xmu
re2=rocas*ucas*x2/xmu
nu=0.02063*abs(re2**0.8-re1**0.8)/0.8
heff=arnod(ipst,i1,i2)/((abs(x2-x1)/(nu*xk))+splen(ipst,
\$i1,i2))
tc=t0cas
endif
if(twcas.ne.0.and.i2.eq.3) then
tout=t0cas
tnode=rrvp(ipel)
tsurfo=((tout-tnode)*heff*splen(ipst,i1,i2))+tnode
tsurf=(tsurfo*(1.-wfstrf))+(wfstrf*twcas)
hcor=(tsurf-tnode)/(splen(ipst,i1,i2)*(tout-tsurf))
heff=1./((1./abs(hcor))+splen(ipst,i1,i2))
endif
twc=twbs(ns)
if(twc.gt.0..and.i2.eq.4) then
tout=tt3c(ns)
tnode=rrvp(ipel)
tsurfo=((tout-tnode)*heff*splen(ipst,i1,i2))+tnode
tsurf=(tsurfo*(1.-wfstrf))+(wfstrf*twc)
hcor=(tsurf-tnode)/(splen(ipst,i1,i2)*(tout-tsurf))
heff=1./((1./abs(hcor))+splen(ipst,i1,i2))
endif
vtmp(i2)=heff*con
c      write(*,*)'210:i1,i2,nadj,n3,heff,con:',i1,i2,nadj,n3,heff,con
if(n3.eq.-74.and.i2.eq.3)tc=t0cas
if(n3.eq.-74.and.i2.eq.4)tc=trotor
aos=aos+vtmp(i2)
if(n3.gt.0)ajtj=ajtj+(vtmp(i2)*rrvp(n3))
if(n3.gt.0.or.n3.eq.-75)goto 210
aktk=aktk+(tc*vtmp(i2))
vtmp(i2)=0.
210  continue
c      read(*,3)rkey
do214i2=1,nadj
n3=nnv(i2)
213  if(n3.lt.0)goto 214
val=-vtmp(i2)
jpc=n3
call spear(nemax,ipel,jpc,nele,lcu,lmax,inl,val,vl,2,ier)

```

```

ichk=213
if(ier.ne.0)goto1005
214 continue
rrv(ipel)=(rrvp(ipel)*(1.-aos))+ajtj+(aktk*2.)
vc=1.+aos
call spear(nemax,ipel,ipel,nele,lcur,lmax,inl,vc,vl,2,ier)
ichk=214
if(ier.ne.0)goto1005
220 continue
c solution of equations
call spmsol(nele,lmax,nemax,inl,vl,rrv,cwork)
c for (nrotcs=3), check evaporation and renewal of fluid
if(nrotcs.eq.3) then
rair=8314.3/28.964
do 408i=1,ns
xwmin=txw0(i)*(1.-(pemax*.01))
xwc=txwc(i)
xvc=txw0(i)-txwc(i)
ind=((i-1)*8)+12
tcp=rrvp(ind)
tcnew=rrv(ind)
pb=tpawc(i)
call mixprp(tcp,pb,xvc,xwc,cpm,rhom,xmum,xkm,xkwat)
c boiling temperature
tc=tcnew
tb=tcnew
do402j=1,2
if(tb.le.373.16) then
aa=5.96659
ab=2224.4
endif
if(tb.gt.373.16.and.tb.lt.473.16) then
aa=5.63729
ab=2101.1
endif
if(tb.ge.473.16) then
aa=5.44021
ab=2010.8
endif
tb=ab/(aa-alog10(pb))
402 continue
if(tc.lt.tb) then
ttawc(i)=tc
goto 408
endif
if(tc.gt.645.155) then
txwc(i)=0.
goto403
endif
if(tc.gt.tb) then
c Latent heat of vaporization (J/kg)

```

```

if(tb.lt.373.16)alv=(3169.151-(2.444599*tb))*1000.
if(tb.ge.373.16.and.tb.lt.473.16)alv=(3439.074-(3.16802*tb))
$*1000.
if(tb.ge.473.16.and.tb.lt.573.16)alv=(4473.395-(5.3541*tb))
$*1000.
if(tb.ge.573.16.and.tb.lt.645.155)alv=(12586.86-(19.5984*tb))
$*1000.
delxw=(1.+txw0(i))*cpm*(tc-tb)/alv
xwc=xwc+delxw
txwc(i)=xwc
tc=tb
rrv(ind)=tb
endif
pair=tmasa(i)*rair*tc/(tvol(i)*1.e-5)
tpawc(i)=pair*(1.+(1.609*(txw0(i)-txwc(i))))
ttawc(i)=tc
403 if(txwc(i).le.xwmin) then
c renewal of fluid, if water content goes less than a minimum value
txwc(i)=ttawm(i)
tpawc(i)=tpawm(i)
ttawc(i)=ttawm(i)
rrv(ind)=ttawc(i)
endif
408 continue
endif
return
1005 write(*,*)'err stop in sub tdcoef, ichk,ier,lcu,lmmax= ',
$ichk,ier,lcu,lmmax
stop
end
subroutine mixprp(tkin,pbar,xv,xw,cpm,rhom,xnum,xkm,xkw)
c mixture properties of air+water+vapor (homogeneous fluid model)
c input: tkin(oK)=temp.in degrees Kelvin,pbar=pressure in bar;
c xv=kg_vapor/kg_air,xw=kg_water/kg_air
c output:cpm(J/kg-K)=spec.heat,rhom(kg/m**3)=density;
c xnum(kg/m-s)=dyn.viscosity,xkm(W/m-K)=heat conductivity.
tk=tkin
if(tk.lt.273.16.and.xw.gt.0.) tk=273.16
c water can not remain liquid at temp.<= 0C, property calculation
c is done at 0C.
if(tk.ge.645.16)then
xv=xv+xw
xw=0.
endif
c water and vapor content converted into mass fraction
xm=1.+xv+xw
xxa=1./xm
xxv=xv/xm
xxw=xw/xm
c specific heat (J/kg-K)
ra=8314.3/28.964

```

```

cpa=(3.65359-(1.33736e-3*tk)+(3.29421e-6*tk**2)-(1.91142e-9*tk**3)
$+(0.275462e-12*tk**4))*ra
cpv=1795.419
if(tk.ge.273.16.and.tk.le.473.16)cpv=563.8315+(4.508666*tk)
if(tk.gt.473.16)cpv=-12840.96+(32.83839*tk)
cpw=4183.
if(tk.lt.290.16)cpw=4852.528-(2.305889*tk)
if(tk.gt.373.16.and.tk.le.583.16)cpw=2058.532+(5.641311*tk)
if(tk.gt.583.16)cpw=-77253.31+(142.6763*tk)
cpm=(xxa*cpa)+(xxv*cpv)+(xxw*cpw)
c density(kg/m**3)
rhom=pbar*1.e5/(tk*ra)*xm
c viscosity coefficients (kg/m-K)
if(tk.le.573.16)xmuv=(-0.3970778+(0.03456057*tk))*1.e-6
if(tk.gt.573.16.and.tk.le.645.16)xmuv=(-169.9568+(0.3303916*tk))
$*1.e-6
if(tk.gt.645.16)xmuv=4.3199e-5*(tk/645.16)**0.6
if(tk.lt.293.16)xmuw=(12571.45-(39.56894*tk))*1.e-6
if(tk.ge.293.16.and.tk.lt.373.16)xmuw=(3547.392-(8.786854*tk))
$*1.e-6
if(tk.ge.373.16)xmuw=(1210.4-(3.51718*tk)+(2.661133e-3*tk**2))
$*1.e-6
xmua=1.872e-5*(tk/300.)**.6
xmum=(xxv*xmuv)+(xxa*xmua)+(xxw*xmuw)
c heat conductivity coefficient (W/m-K)
xka=xmua*cpa/0.71
if(tk.lt.473.16)xkv=(-15.04779+(0.1140167*tk))*0.001
if(tk.ge.473.16.and.tk.lt.573.16)xkv=(-105.84+(0.3059*tk))*0.001
if(tk.ge.573.16.and.tk.le.645.16)xkv=(-10673.88+(18.74326*tk))
$*0.001
if(tk.gt.645.16)xkv=1.419*(tk/645.16)**0.6
if(tk.lt.573.16)xkw=(596.9995+(0.02097965*tk))*0.001
if(tk.ge.573.16)xkw=(-5838.816+(11.24961*tk))*0.001
xkm=(xxv*xkv)+(xxa*xka)+(xxw*xkw)
return
end

```

APPENDIX D

File 1: A1: case1.inp (for dry air)

Input Data - Dry Case

0.450
01
01
01
00
02 00 02 00
06.95 07.64
2.520 2.453
2.170 2.436
1.909 2.383
36.00 26.00
49.20 51.40
37.20 38.10
18.10 18.50
07.35 08.10 08.73
2.142 1.844 1.617
1.880 1.665 1.484
1.563 1.451 1.326
36.00 40.00 46.00
37.00 37.80 37.90
28.70 30.90 31.80
20.80 23.90 25.40
1.000 0.715
1.106 0.891
1.541 1.260
0.857 0.834 0.853
0.958 0.929 0.940
1.198 1.125 1.099
32.03 33.20 32.39
23.91 25.81 26.12
12.54 14.46 16.02
1.00
0.000 1 0.000 1 0
0602.00 0597.00 1944.00
0020.0 0600.0
08879.0 0602.00 1944.00 08879.0 08879.0
0.000 0000.00000
028.970 18.000 16.00
050.0 00300.0
0.57700 0.72800
0.79000 0.86000
14.469 14.237
14.366 14.116 13.913
2
14.47 14.24
11.28 11.30
6.947 7.639
14.47 14.24
14.37 14.12

11.21 11.36
07.35 08.10
14.37 14.12
0.985 0.950
0.945 0.955 0.965
1 1 2
51.00 56.15
42.70 45.60
37.90 31.85
47.40 46.65
31.70 30.60
-1.70 5.150
54.22 54.00 55.65
40.40 43.95 46.25
37.00 41.75 45.00
26.22 26.80 25.05
17.00 17.85 17.35
04.60 06.05 05.80
011.300000 000.0000000
1.288 1.232
1.254 1.233
1.277 1.201
1.277 1.222
1.248 1.227
1.262 1.184
0.886 0.943
0.912 0.962
0.911 0.927
00.3758249 00.3220294
00.3386056 00.2975193
00.3498541 00.2657488
00.3650267 00.3138522 00.2768841
00.3095849 00.2832251 00.2416014
00.2780559 00.2453565 00.2246608
080.00
0.0010 0.0010
04.503 04.534
2
02116.2 00518.7
2.3000 1.4600
0.0900 0.0900
1.0000 1.5000
588.5 576.6 558.3
653.9 634.6 625.3
613.4 725.9 684.6
526.5 511.4 502.8
632.0 606.5 591.6
722.3 729.5 680.0
560.5 543.5
623.2 610.3
718.2 676.2

0.3759 0.3219
0.3692 0.3241
0.3290 0.2545
done

APPENDIX D

File 2: A2:case2.inp (for air with 4 percent water)

Input Data - Wet Case 1

0.450
01
01
02
04
02 00 02 00
06.95 07.64
2.520 2.453
2.170 2.436
1.909 2.383
36.00 26.00
49.20 51.40
37.20 38.10
18.10 18.50
07.35 08.10 08.73
2.142 1.844 1.617
1.880 1.665 1.484
1.563 1.451 1.326
36.00 40.00 46.00
37.00 37.80 37.90
28.70 30.90 31.80
20.80 23.90 25.40
1.000 0.715
1.106 0.891
1.541 1.260
0.857 0.834 0.853
0.958 0.929 0.940
1.198 1.125 1.099
32.03 33.20 32.39
23.91 25.81 26.12
12.54 14.46 16.02
1.00
0.000 1 1.000 1 0
0602.00 0597.00 1944.00
0020.0 0600.0
08879.0 0602.00 1944.00 08879.0 08879.0
0.000 0000.00000
028.970 18.000 16.00
050.0 00300.0
0.57700 0.72800
0.79000 0.86000
14.469 14.237
14.366 14.116 13.913
2
14.47 14.24
11.28 11.30
6.947 7.639
14.47 14.24
14.37 14.12

11.21 11.36
07.35 08.10
14.37 14.12
0.985 0.950
0.945 0.955 0.965
1 1 2
51.00 56.15
42.70 45.60
37.90 31.85
47.40 46.65
31.70 30.60
-1.70 5.15
54.22 54.00 55.65
40.40 43.95 46.25
37.00 41.75 45.00
26.22 26.80 25.05
17.00 17.85 17.35
04.60 06.05 05.80
011.300000 000.0000000
1.288 1.232
1.254 1.233
1.277 1.201
1.277 1.222
1.248 1.227
1.262 1.184
0.886 0.943
0.912 0.962
0.911 0.927
00.3758249 00.3220294
00.3386056 00.2975193
00.3498541 00.2657488
00.3650267 00.3138522 00.2768841
00.3095849 00.2832251 00.2416014
00.2780559 00.2453565 00.2246608
080.00
0.0010 0.0010
04.503 04.534
2
02116.2 00518.7
2.3000 1.4600
0.0900 0.0900
1.0000 1.5000
588.5 576.6 558.3
653.9 634.6 625.3
613.4 725.9 684.6
526.5 511.4 502.8
632.0 606.5 591.6
722.3 729.5 680.0
560.5 543.5
623.2 610.3
718.2 676.2

0.375 90.3219
0.369 20.3241
0.329 00.2545
done

APPENDIX D

File 3: B1: blheat1.inp (for solid rotor disk)

2 0 7 4 1
2 4 2.4145E+02
-75 6 -72 -76
9.2520E-04 9.2520E-04 2.7860E-03 2.4660E-03
4.7800E-04 7.6910E-04 2.7710E-04 2.7710E-04
12 4 1.6219E+02
-75 3 -73 -72
2.6280E-03 2.6280E-03 1.4020E-03 1.2260E-03
1.2460E-04 2.8170E-04 2.4930E-04 2.4930E-04
14 4 2.0453E+02
2 9 -73 4
2.6280E-03 2.6280E-03 1.7680E-03 1.5460E-03
2.8170E-04 5.4300E-04 2.4930E-04 3.5380E-03
6 2 1.3700E+01
3 -72
1.5460E-03 1.0350E-02
3.5380E-03 5.6540E-04
7
6 2 3.4170E+01
6 -71
1.3520E-03 2.1190E-02
5.0520E-03 6.8900E-05
11 4 1.1540E+02
1 8 5 7
9.2520E-04 9.2520E-04 1.3520E-03 1.1580E-03
7.6910E-04 8.2630E-04 5.0520E-03 2.7710E-04
15 2 1.1943E+02
6 -76
1.1580E-03 3.1290E-03
5.0530E-04 1.9404E-04
2 4 2.8021E+02
6 13 -72 -76
9.2520E-04 1.1820E-03 3.0470E-03 2.6320E-03
8.2630E-04 9.0380E-04 2.7710E-04 2.7710E-04
12 4 5.8508E+02
3 10 -73 -71
2.6280E-03 3.4610E-03 4.9390E-03 4.3270E-03
5.4300E-04 5.7260E-04 2.4930E-04 2.4930E-04
14 4 3.5465E+02
9 16 -73 11
5.3460E-03 5.3460E-03 3.0600E-03 2.6860E-02
5.9260E-04 6.1760E-04 2.4930E-04 4.7070E-03
6 2 2.9360E+01
10 -72
2.6860E-03 1.7510E-02
4.7070E-03 7.1630E-05
7
6 2 3.7990E+01
13 -71

2.6070E-03 2.0980E-02
 4.4680E-03 7.7340E-05
 11 4 2.2407E+02
 8 15 12 14
 1.1820E-03 1.1820E-03 2.6070E-03 2.2660E-03
 9.0380E-04 9.2270E-04 4.4680E-03 2.7710E-04
 15 2 2.4196E+02
 13 -76
 2.2660E-03 5.1180E-03
 5.0530E-04 2.4580E-04
 2 4 3.5765E+02
 12 -75 -72 -76
 1.1820E-03 1.1820E-03 4.1450E-02 3.6320E-03
 9.2270E-04 5.5410E-04 2.7710E-04 2.7710E-04
 12 4 7.5884E+02
 10 17 -73 -71
 3.4610E-03 3.0640E-03 6.5450E-03 5.7390E-03
 6.1760E-04 6.4890E-04 2.4930E-04 2.4930E-04
 14 4 2.7030E+02
 16 19 -73 18
 3.0640E-03 3.0640E-03 2.3340E-03 2.0450E-03
 6.4890E-04 3.0260E-04 2.4930E-04 4.0720E-03
 6 2 1.9880E+01
 17 -72
 2.0450E-03 1.3390E-02
 4.0720E-03 6.3440E-05
 12 4 1.8915E+02
 17 -75 -73 -72
 3.0640E-03 3.0640E-03 1.6340E-03 1.4310E-03
 3.0260E-04 1.2460E-04 2.4930E-04 2.4930E-04
 0.0000E+00 0.0000E+00
 0.0000E+00 2.8380E+00
 0.0000E+00 1.0000E+00
 0.0000E+00 0.0000E+00
 1.0000E+00 2.2610E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 2.8380E+00 4.6660E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 4.6660E+00 7.8440E+00
 2.2610E+00 5.3560E+00
 0.0000E+00 0.0000E+00
 5.3560E+00 7.0160E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00

0.0000E+00	0.0000E+00
7.8440E+00	1.0033E+01
0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00
1.0033E+01	1.3322E+01
7.0160E+00	1.0793E+01
0.0000E+00	0.0000E+00
1.0793E+01	1.2222E+01
0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00
1.2222E+01	1.3222E+01
0.0000E+00	0.0000E+00
5.88000E-06	
2 9	14.477 2.950
5 6	
1.1760E-05	1.1760E-05
7.5200E+00	6.9500E+00
2 16	14.247 3.640
12 13	
1.1760E-05	1.1760E-05
6.6000E+00	7.6400E+00

APPENDIX D

File 4: B2:blheat2.inp (for rotor disk internally cooled with dry air)

2 0 7 4 2
 2 4 2.4145E+02
 -75 6 -72 -76
 9.2520E-04 9.2520E-04 2.7860E-03 2.4660E-03
 4.7800E-04 7.6910E-04 2.7710E-04 2.7710E-04
 12 4 1.6219E+02
 -75 3 -73 -72
 2.6280E-03 2.6280E-03 1.4020E-03 1.2260E-03
 1.2460E-04 2.8170E-04 2.4930E-04 2.4930E-04
 14 4 2.0453E+02
 2 9 -73 4
 2.6280E-03 2.6280E-03 1.7680E-03 1.5460E-03
 2.8170E-04 5.4300E-04 2.4930E-04 3.5380E-03
 6 2 1.3700E+01
 3 -72
 1.5460E-03 1.0350E-02
 3.5380E-03 5.6540E-04
 7
 6 2 3.4170E+01
 6 -71
 1.3520E-03 2.1190E-02
 5.0520E-03 6.8900E-05
 11 4 1.1540E+02
 1 8 5 7
 9.2520E-04 9.2520E-04 1.3520E-03 1.1580E-03
 7.6910E-04 8.2630E-04 5.0520E-03 2.7710E-04
 16 3 6.5591e+02
 6 -76 -77
 6.9460e-03 1.8770e-02 1.3400e-03
 5.0530E-04 1.9404E-04 6.5410e-05
 2 4 2.8021E+02
 6 13 -72 -76
 9.2520E-04 1.1820E-03 3.0470E-03 2.6320E-03
 8.2630E-04 9.0380E-04 2.7710E-04 2.7710E-04
 12 4 5.8508E+02
 3 10 -73 -71
 2.6280E-03 3.4610E-03 4.9390E-03 4.3270E-03
 5.4300E-04 5.7260E-04 2.4930E-04 2.4930E-04
 14 4 3.5465E+02
 9 16 -73 11
 5.3460E-03 5.3460E-03 3.0600E-03 2.6860E-02
 5.9260E-04 6.1760E-04 2.4930E-04 4.7070E-03
 6 2 2.9360E+01
 10 -72
 2.6860E-03 1.7510E-02
 4.7070E-03 7.1630E-05
 7
 6 2 3.7990E+01
 13 -71
 2.6070E-03 2.0980E-02

4.4680E-03 7.7340E-05
 11 4 2.2407E+02
 8 15 12 14
 1.1820E-03 1.1820E-03 2.6070E-03 2.2660E-03
 9.0380E-04 9.2270E-04 4.4680E-03 2.7710E-04
 16 3 1.1970e+03
 13 -76 -77
 1.1800e-03 2.6610e-02 1.3400e-03
 5.0530E-04 2.4580E-04 7.5550e-05
 2 4 3.5765E+02
 12 -75 -72 -76
 1.1820E-03 1.1820E-03 4.1450E-02 3.6320E-03
 9.2270E-04 5.5410E-04 2.7710E-04 2.7710E-04
 12 4 7.5884E+02
 10 17 -73 -71
 3.4610E-03 3.0640E-03 6.5450E-03 5.7390E-03
 6.1760E-04 6.4890E-04 2.4930E-04 2.4930E-04
 14 4 2.7030E+02
 16 19 -73 18
 3.0640E-03 3.0640E-03 2.3340E-03 2.0450E-03
 6.4890E-04 3.0260E-04 2.4930E-04 4.0720E-03
 6 2 1.9880E+01
 17 -72
 2.0450E-03 1.3390E-02
 4.0720E-03 6.3440E-05
 12 4 1.8915E+02
 17 -75 -73 -72
 3.0640E-03 3.0640E-03 1.6340E-03 1.4310E-03
 3.0260E-04 1.2460E-04 2.4930E-04 2.4930E-04
 0.0000E+00 0.0000E+00
 0.0000E+00 2.8380E+00
 0.0000E+00 1.0000E+00
 0.0000E+00 0.0000E+00
 1.0000E+00 2.2610E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 2.8380E+00 4.6660E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 4.6660E+00 7.8440E+00
 2.2610E+00 5.3560E+00
 0.0000E+00 0.0000E+00
 5.3560E+00 7.0160E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00

0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
7.8440E+00 1.0033E+01
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
1.0033E+01 1.3322E+01
7.0160E+00 1.0793E+01
0.0000E+00 0.0000E+00
1.0793E+01 1.2222E+01
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
1.2222E+01 1.3222E+01
0.0000E+00 0.0000E+00
5.88000E-06
2 9 14.477 2.950
5 6
1.1760E-05 1.1760E-05
7.5200E+00 6.9500E+00
2 16 14.247 3.640
12 13
1.1760E-05 1.1760E-05
6.6000E+00 7.6400E+00
3.05 5.85 1.676e-3 0.288. 1.1
3.44 6.54 1.676e-3 0.288. 1.1
5.e-6

APPENDIX D

File 5: B3:blheat3.inp
(for rotor disk internally cooled with air-water mixture)

2 0 7 4 2
 2 4 2.4145E+02
 -75 6 -72 -76
 9.2520E-04 9.2520E-04 2.7860E-03 2.4660E-03
 4.7800E-04 7.6910E-04 2.7710E-04 2.7710E-04
 12 4 1.6219E+02
 -75 3 -73 -72
 2.6280E-03 2.6280E-03 1.4020E-03 1.2260E-03
 1.2460E-04 2.8170E-04 2.4930E-04 2.4930E-04
 14 4 2.0453E+02
 2 9 -73 4
 2.6280E-03 2.6280E-03 1.7680E-03 1.5460E-03
 2.8170E-04 5.4300E-04 2.4930E-04 3.5380E-03
 6 2 1.3700E+01
 3 -72
 1.5460E-03 1.0350E-02
 3.5380E-03 5.6540E-04
 7
 6 2 3.4170E+01
 6 -71
 1.3520E-03 2.1190E-02
 5.0520E-03 6.8900E-05
 11 4 1.1540E+02
 1 8 5 7
 9.2520E-04 9.2520E-04 1.3520E-03 1.1580E-03
 7.6910E-04 8.2630E-04 5.0520E-03 2.7710E-04
 16 3 6.5591e+02
 6 -76 -77
 6.9460e-03 1.8770e-02 1.3400e-03
 5.0530E-04 1.9404E-04 6.5410e-05
 2 4 2.8021E+02
 6 13 -72 -76
 9.2520E-04 1.1820E-03 3.0470E-03 2.6320E-03
 8.2630E-04 9.0380E-04 2.7710E-04 2.7710E-04
 12 4 5.8508E+02
 3 10 -73 -71
 2.6280E-03 3.4610E-03 4.9390E-03 4.3270E-03
 5.4300E-04 5.7260E-04 2.4930E-04 2.4930E-04
 14 4 3.5465E+02
 9 16 -73 11
 5.3460E-03 5.3460E-03 3.0600E-03 2.6860E-02
 5.9260E-04 6.1760E-04 2.4930E-04 4.7070E-03
 6 2 2.9360E+01
 10 -72
 2.6860E-03 1.7510E-02
 4.7070E-03 7.1630E-05
 7
 6 2 3.7990E+01
 13 -71
 2.6070E-03 2.0980E-02

4.4680E-03 7.7340E-05
 11 4 2.2407E+02
 8 15 12 14
 1.1820E-03 1.1820E-03 2.6070E-03 2.2660E-03
 9.0380E-04 9.2270E-04 4.4680E-03 2.7710E-04
 16 3 1.1970e+03
 13 -76 -77
 1.1800e-03 2.6610e-02 1.3400e-03
 5.0530E-04 2.4580E-04 7.5550e-05
 2 4 3.5765E+02
 12 -75 -72 -76
 1.1820E-03 1.1820E-03 4.1450E-02 3.6320E-03
 9.2270E-04 5.5410E-04 2.7710E-04 2.7710E-04
 12 4 7.5884E+02
 10 17 -73 -71
 3.4610E-03 3.0640E-03 6.5450E-03 5.7390E-03
 6.1760E-04 6.4890E-04 2.4930E-04 2.4930E-04
 14 4 2.7030E+02
 16 19 -73 18
 3.0640E-03 3.0640E-03 2.3340E-03 2.0450E-03
 6.4890E-04 3.0260E-04 2.4930E-04 4.0720E-03
 6 2 1.9880E+01
 17 -72
 2.0450E-03 1.3390E-02
 4.0720E-03 6.3440E-05
 12 4 1.8915E+02
 17 -75 -73 -72
 3.0640E-03 3.0640E-03 1.6340E-03 1.4310E-03
 3.0260E-04 1.2460E-04 2.4930E-04 2.4930E-04
 0.0000E+00 0.0000E+00
 0.0000E+00 2.8380E+00
 0.0000E+00 1.0000E+00
 0.0000E+00 0.0000E+00
 1.0000E+00 2.2610E+00
 0.0000E+00 0.0000E+00
 2.8380E+00 4.6660E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 4.6660E+00 7.8440E+00
 2.2610E+00 5.3560E+00
 0.0000E+00 0.0000E+00
 5.3560E+00 7.0160E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00

0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
7.8440E+00 1.0033E+01
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
1.0033E+01 1.3322E+01
7.0160E+00 1.0793E+01
0.0000E+00 0.0000E+00
1.0793E+01 1.2222E+01
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
1.2222E+01 1.3222E+01
0.0000E+00 0.0000E+00
5.88000E-06
2 9 14.477 2.950
5 6
1.1760E-05 1.1760E-05
7.5200E+00 6.9500E+00
2 16 14.247 3.640
12 13
1.1760E-05 1.1760E-05
6.6000E+00 7.6400E+00
3.05 5.85 1.676e-3 .08 288. 1.1
3.44 6.54 1.676e-3 .08 288. 1.1
5.0000E-6

APPENDIX D

**File 6: B4: blheat4.inp
(for rotor disk internally cooled with stagnant air-water mixture renewed
periodically)**

2 0 7 4 3
 2 4 2.4145E+02
 -75 6 -72 -76
 9.2520E-04 9.2520E-04 2.7860E-03 2.4660E-03
 4.7800E-04 7.6910E-04 2.7710E-04 2.7710E-04
 12 4 1.6219E+02
 -75 3 -73 -72
 2.6280E-03 2.6280E-03 1.4020E-03 1.2260E-03
 1.2460E-04 2.8170E-04 2.4930E-04 2.4930E-04
 14 4 2.0453E+02
 2 9 -73 4
 2.6280E-03 2.6280E-03 1.7680E-03 1.5460E-03
 2.8170E-04 5.4300E-04 2.4930E-04 3.5380E-03
 6 2 1.3700E+01
 3 -72
 1.5460E-03 1.0350E-02
 3.5380E-03 5.6540E-04
 8
 6 2 3.4170E+01
 6 -71
 1.3520E-03 2.1190E-02
 5.0520E-03 6.8900E-05
 11 4 1.1540E+02
 1 8 5 7
 9.2520E-04 9.2520E-04 1.3520E-03 1.1580E-03
 7.6910E-04 8.2630E-04 5.0520E-03 2.7710E-04
 16 3 6.5591e+02
 6 -76 -77
 6.9460e-03 1.8770e-02 1.3400e-03
 5.0530E-04 1.9404E-04 6.5410e-05
 2 4 2.8021E+02
 6 14 -72 -76
 9.2520E-04 1.1820E-03 3.0470E-03 2.6320E-03
 8.2630E-04 9.0380E-04 2.7710E-04 2.7710E-04
 12 4 5.8508E+02
 3 10 -73 -71
 2.6280E-03 3.4610E-03 4.9390E-03 4.3270E-03
 5.4300E-04 5.7260E-04 2.4930E-04 2.4930E-04
 14 4 3.5465E+02
 9 17 -73 11
 5.3460E-03 5.3460E-03 3.0600E-03 2.6860E-02
 5.9260E-04 6.1760E-04 2.4930E-04 4.7070E-03
 6 2 2.9360E+01
 10 -72
 2.6860E-03 1.7510E-02
 4.7070E-03 7.1630E-05
 8 1 0.0000E+00
 -77
 1.3400e-3
 6.5410e-5

8
 6 2 3.7990E+01
 14 -71
 2.6070E-03 2.0980E-02
 4.4680E-03 7.7340E-05
 11 4 2.2407E+02
 8 16 13 15
 1.1820E-03 1.1820E-03 2.6070E-03 2.2660E-03
 9.0380E-04 9.2270E-04 4.4680E-03 2.7710E-04
 16 3 1.1970e+03
 14 -76 -77
 1.1800e-03 2.6610e-02 1.3400e-03
 5.0530E-04 2.4580E-04 7.5550e-05
 2 4 3.5765E+02
 14 -75 -72 -76
 1.1820E-03 1.1820E-03 4.1450E-02 3.6320E-03
 9.2270E-04 5.5410E-04 2.7710E-04 2.7710E-04
 12 4 7.5884E+02
 10 18 -73 -71
 3.4610E-03 3.0640E-03 6.5450E-03 5.7390E-03
 6.1760E-04 6.4890E-04 2.4930E-04 2.4930E-04
 14 4 2.7030E+02
 17 21 -73 19
 3.0640E-03 3.0640E-03 2.3340E-03 2.0450E-03
 6.4890E-04 3.0260E-04 2.4930E-04 4.0720E-03
 6 2 1.9880E+01
 18 -72
 2.0450E-03 1.3390E-02
 4.0720E-03 6.3440E-05
 8 1 0.0000E+00
 -77
 1.3400E-03
 7.5550E-05
 12 4 1.8915E+02
 18 -75 -73 -72
 3.0640E-03 3.0640E-03 1.6340E-03 1.4310E-03
 3.0260E-04 1.2460E-04 2.4930E-04 2.4930E-04
 0.0000E+00 0.0000E+00
 0.0000E+00 2.8380E+00
 0.0000E+00 1.0000E+00
 0.0000E+00 0.0000E+00
 1.0000E+00 2.2610E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00
 2.8380E+00 4.6660E+00
 0.0000E+00 0.0000E+00
 0.0000E+00 0.0000E+00

0.0000E+00 0.0000E+00
4.6660E+00 7.8440E+00
2.2610E+00 5.3560E+00
0.0000E+00 0.0000E+00
5.3560E+00 7.0160E+00
0.0000E+00 0.0000E+00
7.8440E+00 1.0033E+01
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
1.0033E+01 1.3322E+01
7.0160E+00 1.0793E+01
0.0000E+00 0.0000E+00
1.0793E+01 1.2222E+01
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
1.2222E+01 1.3222E+01
0.0000E+00 0.0000E+00
5.88000E-06
2 9 14.477 2.950
5 6
1.1760E-05 1.1760E-05
7.5200E+00 6.9500E+00
2 17 14.247 3.640
13 14
1.1760E-05 1.1760E-05
6.6000E+00 7.6400E+00
3.05 5.85 1.676e-3 .08 288. 1.1
3.44 6.54 1.676e-3 .08 288. 1.1
5.0000E-06
50.

APPENDIX E

File 1: case1.out

Input Data - Dry Case
Compressor flow adiabatic
icase= 0

phi design = 0.7773584

inlet phi =0.4500000
0psi= 9.1772E-01 psi1= 7.4815E-01 loss= 1.6957E-01
jsweep= 100

MEAN

fraction of design speed = 1.00000
>>>>>> loop number 2 <<<<<<<
igv area= 0.241601
nhg number of streamlines = 10.22089
1 ***** input data

heat transfer after rotor and stator version
0 number of stages= 2 (fan 0, lpc 2, hpc 0)
performance at mean
0 vapor is centrifuged
0 large droplets in rotor free stream are not centrifuged

stage	1	2	3
rrhub(i)	6.95	7.64	
rc(i)	2.170	2.436	
rblade(i)	36.00	26.00	
stager(i)	37.20	38.10	
stages(i)	28.70	30.90	31.80
srrhub(i)	7.35	8.10	8.73
sc(i)	1.880	1.665	1.484
sblade(i)	36.00	40.00	46.00
sigumr(i)	1.106	0.891	
sigurns(i)	0.958	0.929	0.940
bet2ss(i)	23.91	25.81	26.12
gapr(i)	0.577	0.728	
gaps(i)	0.790	0.860	
rrtip(i)	14.47	14.24	
srtip(i)	14.37	14.12	13.91
rt(i)	14.47	14.24	
rm(i)	11.28	11.30	
rh(i)	6.95	7.64	
st(i)	14.37	14.12	
sm(i)	11.21	11.36	
sh(i)	7.35	8.10	
block(i)	0.985	0.950	
blocks(i)	0.945	0.955	0.965
bet1mr(i)	42.70	45.60	
bet2mr(i)	31.70	30.60	

bet1ms(i) 40.40 43.95 46.25
bet2ms(i) 17.00 17.85 17.35
pr12d(i) 1.254 1.233
pr13d(i) 1.248 1.227
etard(i) 0.912 0.962
dvz1(i) 653.9 634.6 625.3
dvz2(i) 632.0 606.5 591.6
dvz3(i) 623.2 610.3
ak1(i) 2.300 1.460
ak2(i) 0.090 0.090
ak3(i) 1.000 1.500

1 ***** input data *****
0 fmf(fraction of design corrected speed)=1.000
0 xdin(initial water content of small droplet)=0.000
xddin(initial water content of large droplet)=0.000
rhumid(initial relative humidity)= 0.00 per cent
xch4(initial methane content)=0.000
0 t0g(compressor inlet total temprature of gas)= 602.00
t0w(compressor inlet temperature of droplet)= 597.00
p0(compressor inlet total pressure)=1944.00
0 din(initial droplet diameter of small droplet)= 20.0
ddin(initial droplet diameter of large droplet)= 600.0
0 fnd(design rotational speed)= 8879.0
0 dsmass(design stream mass flow rate)= 11.3000
0 bypass ratio = 0.0000
0 compressor inlet total temperature(gas phase) 602.00 r
0 compressor inlet total pressure=1944.00 lb/ft**2
0 preb(percent of water that rebound after impingement)= 50.0 percent
0 rotor speed= 9565.4 rpm
0 corrected rotor speed= 8879.0 rpm(100.0 per cent of design corrected speed)
0 molecular weight of air= 28.9700
0 maximum diameter of small droplets= 300.0 microns
0 rotor corrected speed at design point= 8879.0
rotor corrected speed of lpc at design point= 8879.0
rotor corrected speed of hpc at the design point= 8879.0
design flow coefficient at inlet = 0.777358

1***** design point information *****
0 ***** compressor inlet *****
0 total temperature at compressor inlet(R)= 602.00000
total pressure at compressor inlet(lbf/ft**2)= 1944.00
static temperature at compressor inlet(R)= 556.98975
static pressure at compressor inlet(lbf/ft**2)= 1480.37
static density at compressor inlet(lbm/ft**3)= 0.04982
0 acoustic speed at compressor inlet(ft/s)=1156.55713
axial velocity at compressor inlet(ft/s)= 625.29999
mach number at compressor inlet= -0.63642
streamtube area at compressor inlet(ft**2)= 0.24160
flow coefficient at compressor inlet= 0.77736
1***** design point information *****
0 ***** stage= 1 *****

	total	total	static	static	static	
	temp	pressure	temp	pressure	density	
0 rotor inlet	602.000	1944.000	554.852	1460.540	0.049	
rotor outlet	646.018	2437.776	582.467	1694.070	0.055	
0	axial	absolute	relative	tan comp	tan comp	
	velocity	velocity	velocity	of abs vel	of rel vel	
0 rotor inlet	653.90002	728.27600	901.76440	320.62540	620.96191	
rotor outlet	632.00000	875.68225	762.34113	606.13159	329.61261	
0	rotor	abs mach	rel mach	rel total	rel total	
	speed	number	number	temp	pressure	
0 rotor inlet	941.587	0.653	0.781	622.410	2185.063	
rotor outlet	935.744	0.741	0.645	630.648	5747.708	
0	abs flow	rel flow	streamtube	flow		
	angle	angle	area	radius	coefficient	
0 rotor inlet	26.12000	43.52000	0.33861	11.28000	0.54140	
rotor outlet	43.80309	25.61799	0.30958	11.21000	0.52327	
0 stage total pressure ratio at design point=	1.24800					
stage adiabatic efficiency at design point=	0.89109					
rotor total pressure ratio at design point=	1.25400					
rotor adiabatic efficiency at design point=	0.91200					
rotor total temperature ratio at design point=	1.07312					
1***** design point information *****						
0 ***** stage= 2 *****						
0	total	total	static	static	static	
	temp	pressure	temp	pressure	density	
0 rotor inlet	646.018	2426.112	606.280	1941.056	0.060	
rotor outlet	687.268	2991.396	632.514	2232.765	0.066	
0	axial	absolute	relative	tan comp	tan comp	
	velocity	velocity	velocity	of abs vel	of rel vel	
0 rotor inlet	634.59998	694.17151	916.97321	281.34848	661.90845	
rotor outlet	606.50000	813.80762	725.84167	542.62378	405.64148	
0	rotor	abs mach	rel mach	rel total	rel total	
	speed	number	number	temp	pressure	
0 rotor inlet	943.257	0.574	0.760	675.988	2845.161	
rotor outlet	948.265	0.661	0.589	676.086	6382.674	
0	abs flow	rel flow	streamtube	flow		
	angle	angle	area	radius	coefficient	
0 rotor inlet	23.91000	46.20665	0.29752	11.30000	0.53399	
rotor outlet	41.81838	33.97677	0.28323	11.36000	0.51034	
0 stage total pressure ratio at design point=	1.22700					
stage adiabatic efficiency at design point=	0.93777					
rotor total pressure ratio at design point=	1.23300					
rotor adiabatic efficiency at design point=	0.96200					
rotor total temperature ratio at design point=	1.06385					
1***** design point information *****						
0***** overall performance at design point ****						
0 compressor inlet total temperature=	602.00					
0 compressor inlet total pressure=	1944.00					
0 corrected mass flow rate=	135.446					
0 overall total pressure ratio=	1.5313					
0 overall total temperature ratio=	1.1416					

0 overall adiabatic efficiency=0.9102
 0 overall temperature rise= 85.268
 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
 bet1sr(i) 43.52 46.21
 bet2sr(i) 25.62 33.98
 aincsr(i) 0.82 0.61
 adevsr(i) -6.08 3.38
 bet1ss(i) 43.80 41.82
 bet2ss(i) 23.91 25.81 26.12
 aincss(i) 3.40 -2.13
 adevss(i) 6.91 7.96
 td(i) 602. 646.
 omegr(i) 0.063 0.026
 omegs(i) 0.016 0.019
 sitadr(i) .0399 .0174
 sitads(i) .0120 .0136
 deqr(i) 1.601 1.587
 deqs(i) 1.660 1.523
 1 fai=0.4500000
 xddin = 0.
 nhg main ws(1) tg(1) p(1) rhumid = 0.00000 602.000001944.00000 0.00001
 nhg main xv(1) xwt(1) xch4 = 0.00000 0.00000 0.00000
 0 vz at igv inlet = 543.50366 mach number = 0.46153
 i xwt watrgn
 1 0. 0.
 2 0. 0.
 3 0. 0.
 4 0. 0.
 5 0. 0.
 6 0. 0.
 7 0. 0.
 8 0. 0.
 9 0. 0.
 10 0. 0.
 xv(1) = 1.18659E-09
 watrgt = 0.
 0 istage=0 (igv)
 0 0.45000 543.50366 1.00000
 clear(1)= 1.00000E-03
 nhg main start calculations for stage 1
 d1 dwakem,w2= 0. 514.381
 d2 dwakem,rdelv1= 0. 10.00000
 d3 dwakem,rdelv2= 0. 0.
 ddave(n-2)(n)= 3 0. 0.
 nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000
 nhg ds dl dlge dsll amlge amsll= 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 filmas(1)= 0.
 ui = 0.

hhc = 0.
 htotl = 0.
 1 ***** initial flow coefficient= 0.450 (stage= 1) *****
 0 stage total pressure ratio= 1.35248
 stage total temperature ratio= 1.10863
 stage adiabatic efficiency= 0.82645
 0 stage flow coefficient= 0.305
 axial velocity= 368.37
 rotor speed= 1207.79
 0 *rotor inlet* *rotor outlet* *stator outlet*
 total pressure 1944.0000 2636.5400 2629.2144
 static pressure 1805.3267 2192.1331 2450.7463
 total temperature(gas) 602.0000 667.3978 667.3978
 static temperature(gas) 589.4261 633.1794 654.1548
 static density(gas) 0.0574 0.0649 0.0702
 static density(mixture) 0.0574 0.0649 0.0702
 0 axial velocity 368.3687 336.4398 339.1703
 absolute velocity 389.0349 641.8840 399.3185
 relative velocity 895.7287 514.3813
 blade speed 941.5873 935.7442 943.2569
 tang. comp. of abs. vel. 125.1105 546.6473
 tang. comp. of rel. vel. 816.4768 389.0969
 acoustic speed 1189.7568 1253.3921 1253.3827
 absolute mach number 0.3270 0.5205 0.3186
 relative mach number 0.7529 0.4171
 0 flow coefficient 0.3050 0.2786 0.2854
 flow area 0.3386 0.3280 0.3007
 0 absolute flow angle 18.7592 58.3893 31.8565
 relative flow angle 65.7166 49.1511
 incidence 23.0166 17.9893
 deviation 17.4511 14.8565
 diffusion ratio 3.6653 2.6688
 momentum thickness 0.1314 0.0192
 omega (gas) 0.17564 0.01648
 omega (total) 0.17564 0.01648
 d1 dwakem,v3= 0. 399.318
 d2 dwakem,sdelv1= 0. 10.00000
 d3 dwakem,sdelv2= 0. 0.
 n,ddave(n-2)(n)= 4 0. 0.
 nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000
 nhg ds dl dlge dsll amlge amsll= 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1 ***** initial flow coefficient= 0.450 (istage= 1)

 0 stage total pressure ratio= 1.35248
 stage total temperature ratio= 1.10863
 stage adiabatic efficiency= 0.82645
 stage 1 total ETA 0.82645del T 65.39777

```

Opsi= 5.4154E-01 psi1= 4.4755E-01 loss= 9.3985E-02
0      **stage inlet**   **stage outlet**   **stage outlet**
                                (before inter-    (after inter-
                                stage adjust-    stage adjust-
                                ment)        ment)
xv=      0.00000      0.00000      0.00000
xw=      0.00000      0.00000      0.00000
xww=     0.00000      0.00000      0.00000
xf=      0.00000      0.00000      0.00000
xwt=     0.00000      0.00000      0.00000
xair=    1.00000      1.00000      1.00000
xmetan=  0.00000      0.00000      0.00000
xgas=    1.00000      1.00000      1.00000
wmass=   0.00000      0.00000      0.00000
wwmass=  0.00000      0.00000      0.00000
fmmass=  0.00000      0.00000      0.00000
wtrmass= 0.00000      0.00000      0.00000
amass=   7.16060      7.16060      7.16060
chmass=  0.00000      0.00000      0.00000
vmass=   0.00000      0.00000      0.00000
gmass=   7.16060      7.16060      7.16060
tmass=   7.16060      7.16060      7.16060
ws=      0.00000      0.00000      0.00000
rhoa=   0.06054      0.06333      0.07015
rhom=   0.05453      0.06332      0.07013
rhog=   0.05741      0.06332      0.07013
tg=     602.00000     667.39777     667.39777
tw=     597.00000     597.00000     597.00000
tww=    597.00000     0.00000      597.00000
nhg: tragas, trawat = 1.10863 1.00000
      p= 1944.00000 2636.54004 2629.21436
      tb= 667.26837 0.00000 682.17615
      tdew= 272.00754 274.47519 274.47519

writing to external plot files
clear( 2)= 1.00000E-03
nhg main start calculations for stage 2
d1 dwakem,w2= 0. 581.754
d2 dwakem,rdelv1= 0. 10.00000
d3 dwakem,rdelv2= 0. 0.
ddave(n-2)(n)= 5 0. 0.
nhg wicsiz wmassss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.00000 0.00000 0.00000
0.00000 0.00000 0.00000 0.00000 0.00000
nhg ds dl dlge dsll amlge amsll= 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
nhg wicsiz wmassss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.00000 0.00000
0.00000 0.00000 0.00000 0.00000 0.00000
filmas( 2) = 0.
ui = 0.
hhc = 0.
htot = 0.
1 ***** initial flow coefficient= 0.450 (stage= 2 ) *****
0 stage total pressure ratio= 1.18858

```

stage total temperature ratio= 1.06192
 stage adiabatic efficiency= 0.81180
 0 stage flow coefficient=0.289
 axial velocity= 343.18
 rotor speed=1188.42

0 *rotor inlet* *rotor outlet* *stator outlet*

total pressure	2629.2144	3143.2791	3125.0420	
static pressure	2446.6165	2724.6399	2926.7351	
total temperature(gas)	667.3978	708.7260	708.7260	
static temperature(gas)	653.8803	680.5155	695.6440	
static density(gas)	0.0701	0.0750	0.0789	
static density(mixture)	0.0701	0.0750	0.0789	
0 axial velocity	343.1790	338.8469	322.4617	
absolute velocity	404.0381	583.7838	397.5432	
relative velocity	806.6497	581.7538		
blade speed	943.2569	948.2653	0.0000	
tang. comp. of abs. vel.	213.2487	475.3802		
tang. comp. of rel. vel.	730.0082	472.8851		
acoustic speed	1252.2930	1291.6169	1291.6661	
absolute mach number	0.3226	0.4570	0.3078	
relative mach number	0.6441	0.4554		
0 flow coefficient	0.2888	0.2851	0.2713	
flow area	0.2975	0.2816	0.2816	
0 absolute flow angle	31.8565	54.5191	35.7936	
relative flow angle	64.8217	54.3764		
incidence	19.2217	10.5691		
deviation	23.7764	17.9436		
diffusion ratio	3.9221	3.4434		
momentum thickness	0.0816	0.0371		
omega (gas)	0.13314	0.04356		
omega (total)	0.13314	0.04356		
d1 dwakem,v3=	0.	397.543		
d2 dwakem,sdelv1=	0.	10.00000		
d3 dwakem,sdelv2=	0.	0.		
n,ddave(n-2)(n)=	6	0.	0.	
nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 =	0.00000	0.00000	0.00000	0.00000
0.00000 0.00000 0.00000 0.00000 0.00000				
nhg ds dl dlge dsll amlge amsll=	0.00000	0.00000	0.00000	0.00000
nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 =	0.00000	0.00000	0.00000	
0.00000 0.00000 0.00000 0.00000 0.00000				
1 ***** initial flow coefficient= 0.450 (istage= 2)				

0 stage total pressure ratio=	1.18858			
stage total temperature ratio=	1.06192			
stage adiabatic efficiency=	0.81180			
stage 2 total ETA	0.81378del T	41.32819		
Opsi= 8.8609E-01	psi1= 7.2108E-01	loss= 1.6501E-01		
0 **stage inlet**	**stage outlet**	**stage outlet**		
(before inter-	(after inter-			
stage adjust-	stage adjust-			

	ment)	ment)	
xv=	0.00000	0.00000	0.00000
xw=	0.00000	0.00000	0.00000
xww=	0.00000	0.00000	0.00000
xf=	0.00000	0.00000	0.00000
xwt=	0.00000	0.00000	0.00000
xair=	1.00000	1.00000	1.00000
xmetan=	0.00000	0.00000	0.00000
xgas=	1.00000	1.00000	1.00000
wmass=	0.00000	0.00000	0.00000
wwmass=	0.00000	0.00000	0.00000
fmmass=	0.00000	0.00000	0.00000
wtmass=	0.00000	0.00000	0.00000
amass=	7.16060	7.16060	7.16060
chmass=	0.00000	0.00000	0.00000
vmass=	0.00000	0.00000	0.00000
gmass=	7.16060	7.16060	7.16060
tmass=	7.16060	7.16060	7.16060
ws=	0.00000	0.00000	0.00000
rhoa=	0.07385	0.07516	0.07892
rhom=	0.05453	0.07515	0.07890
rhog=	0.07013	0.07515	0.07890
tg=	667.39777	708.72595	708.72595
tw=	597.00000	597.00000	597.00000
tww=	597.00000	0.00000	597.00000
nhg: tragas, trawat =	1.06192	1.00000	
p=	2629.21436	3143.27905	3125.04199
tb=	682.17615	0.00000	692.03601
tdew=	274.47519	268.01367	268.01367

writing to external plot files

***** overall performance *****

0 initial flow coefficient=0.450

0 corrected speed= 8879.0 1.000 fraction of design corrected speed

0 initial water content(small droplet)=0.000

initial water content(large droplet)=0.000

initial water content(total)=0.000

initial relative humidity= 0.0 per cent

initial methane content=0.000

0 compressor inlet total temperature= 602.00

0 compressor inlet total pressure= 1944.00

0 corrected mass flow rate of mixture= 120.29

0 corrected mass flow rate of gas phase 120.29

0 overall total pressure ratio= 1.6075

0 overall total temperature ratio=1.1773

0 overall adiabatic efficiency=0.8152

***** performance of fan,lpc,hpc *****

0 gas phase stagnation stagnation adiabatic

0 corrected pressure temperature efficiency

0 mass flow ratio ratio

0 fan 0.0000 0.0000 0.0000 0.0000

0 lpc 0.0000 0.0000 0.0000 0.0000

0 hpc 0.0000 0.0000 0.0000 0.0000
0psi= 9.1772E-01 psi1= 7.4815E-01 loss= 1.6957E-01
i= 55
Number of loops = 100
total mass = 1.00000E-08
0psi= 9.1772E-01 psi1= 7.4815E-01 loss= 1.6957E-01
i= 55
gemach = 0.273104

APPENDIX E

File 2: blheat1.out

Compressor flow adiabatic
 initial clearance at ref.temp. (R)= 518.700
 stage 1 : clearance[in]= 7.00092E-03
 stage 2 : clearance[in]= 6.99997E-03

initial steady thermal node and blade clearance
 node no. Node temp.(K):
 1 3.0957E+02 2 3.1387E+02 3 3.1467E+02 4 3.0996E+02 5 3.1591E+02 6
 3.1536E+02 7 3.1469E+02 8 3.2398E+02

9 3.1757E+02 10 3.2224E+02 11 3.2962E+02 12 3.4331E+02 13 3.3565E+02 14
 3.3425E+02 15 3.5303E+02 16 3.2337E+02

17 3.2321E+02 18 3.5220E+02 19 3.2239E+02
 stage 1 : clearance[in]= 4.82655E-03
 stage 2 : clearance[in]= 1.40285E-03

jsweep= 1
 i,T(K):
 1 3.0973E+02 2 3.1399E+02 3 3.1470E+02 4 3.1573E+02 5 3.2717E+02 6
 3.1540E+02 7 3.1469E+02 8 3.2418E+02

9 3.1767E+02 10 3.2240E+02 11 3.3681E+02 12 3.5115E+02 13 3.3570E+02 14
 3.3424E+02 15 3.5519E+02 16 3.2348E+02

17 3.2325E+02 18 3.5983E+02 19 3.2280E+02
 stage 1 : clearance[in]= 3.83663E-03
 stage 2 : clearance[in]= 7.99179E-04

jsweep= 10
 stage 1 : clearance[in]= 3.88718E-03
 stage 2 : clearance[in]= 8.18253E-04

jsweep= 20
 stage 1 : clearance[in]= 3.93486E-03
 stage 2 : clearance[in]= 8.36372E-04

jsweep= 30
 stage 1 : clearance[in]= 3.98064E-03
 stage 2 : clearance[in]= 8.53539E-04

jsweep= 40
 stage 1 : clearance[in]= 4.02260E-03
 stage 2 : clearance[in]= 8.70705E-04

jsweep= 50
 stage 1 : clearance[in]= 4.06456E-03
 stage 2 : clearance[in]= 8.86917E-04

```
jsweep= 60
stage 1 : clearance[in]=  4.10271E-03
stage 2 : clearance[in]=  9.04083E-04
-----
jsweep= 70
stage 1 : clearance[in]=  4.13990E-03
stage 2 : clearance[in]=  9.18388E-04
-----
jsweep= 80
stage 1 : clearance[in]=  4.17519E-03
stage 2 : clearance[in]=  9.32693E-04
-----
jsweep= 90
stage 1 : clearance[in]=  4.20761E-03
stage 2 : clearance[in]=  9.47952E-04
-----
jsweep= 100
i,T(K):
 1 3.0977E+02 2 3.1402E+02 3 3.1473E+02 4 3.1477E+02 5 3.2591E+02 6
 3.1546E+02 7 3.1470E+02 8 3.2424E+02
 9 3.1770E+02 10 3.2262E+02 11 3.3682E+02 12 3.5125E+02 13 3.3577E+02 14
 3.3424E+02 15 3.5568E+02 16 3.2351E+02
 17 3.2333E+02 18 3.5944E+02 19 3.2312E+02
stage 1 : clearance[in]=  3.94630E-03
stage 2 : clearance[in]=  7.85828E-04
```

APPENDIX E

File 3: Case2.out

Input Data - Wet Case 1
Compressor flow adiabatic
icase= 4

phi design = 0.7773584

inlet phi =0.4500000
0psi= 9.1772E-01 psi1= 7.4815E-01 loss= 1.6957E-01
jsweep= 100

MEAN

fraction of design speed = 1.00000
>>>>>>> loop number 2 <<<<<<
igv area= 0.241601
nhg number of streamlines = 10.22089
1 ***** input data

heat transfer after rotor and stator version
0 number of stages= 2 (fan 0, lpc 2, hpc 0)
performance at mean
0 vapor is centrifuged
0 large droplets in rotor free stream are not centrifuged

stage	1	2	3
rrhub(i)	6.95	7.64	
rc(i)	2.170	2.436	
rblade(i)	36.00	26.00	
stager(i)	37.20	38.10	
stages(i)	28.70	30.90	31.80
srhub(i)	7.35	8.10	8.73
sc(i)	1.880	1.665	1.484
sblade(i)	36.00	40.00	46.00
sigumr(i)	1.106	0.891	
sigums(i)	0.958	0.929	0.940
bet2ss(i)	23.91	25.81	26.12
gapr(i)	0.577	0.728	
gaps(i)	0.790	0.860	
rrtip(i)	14.47	14.24	
srtip(i)	14.37	14.12	13.91
rt(i)	14.47	14.24	
rm(i)	11.28	11.30	
rh(i)	6.95	7.64	
st(i)	14.37	14.12	
sm(i)	11.21	11.36	
sh(i)	7.35	8.10	
block(i)	0.985	0.950	
blocks(i)	0.945	0.955	0.965
bet1mr(i)	42.70	45.60	
bet2mr(i)	31.70	30.60	

bet1ms(i) 40.40 43.95 46.25
bet2ms(i) 17.00 17.85 17.35
pr12d(i) 1.254 1.233
pr13d(i) 1.248 1.227
etard(i) 0.912 0.962
dvz1(i) 653.9 634.6 625.3
dvz2(i) 632.0 606.5 591.6
dvz3(i) 623.2 610.3
ak1(i) 2.300 1.460
ak2(i) 0.090 0.090
ak3(i) 1.000 1.500

1 ***** input data *****
0 fnf(fraction of design corrected speed)=1.000
0 xdin(initial water content of small droplet)=0.000
 xddin(initial water content of large droplet)=1.000
 rhumid(initial relative humidity)= 0.00 per cent
 xch4(initial methane content)=0.000
0 t0g(compressor inlet total temprature of gas)= 602.00
 t0w(compressor inlet temperature of droplret)= 597.00
 p0(compressor inlet total pressure)=1944.00
0 din(initial droplet diameter of small droplet)= 20.0
 ddin(initial droplet diameter of large droplet)= 600.0
0 fnd(design rotational speed)= 8879.0
0 dsmass(design stream mass flow rate)= 11.3000
0 bypass ratio = 0.0000
0 compressor inlet total temperature(gas phase) 602.00 r
0 compressor inlet total pressure=1944.00 lb/ft**2
0 preb(percent of water that rebound after impingement)= 50.0 percent
0 rotor speed= 9565.4 rpm
0 corrected rotor speed= 8879.0 rpm(100.0 per cent of design corrected speed)
0 molecular weight of air= 28.9700
0 maximum diameter of small droplets= 300.0 microns
0 rotor corrected speed at design point= 8879.0
 rotor corrected speed of lpc at design point= 8879.0
 rotor corrected speed of hpc at the design point= 8879.0
design flow coefficient at inlet = 0.777358

1***** design point information ***** ***
0 ***** compressor inlet *****
0 total temperature at compressor inlet(R)= 602.00000
 total pressure at compressor inlet(lbf/ft**2)= 1944.00
 static temperature at compressor inlet(R)= 556.98975
 static pressure at compressor inlet(lbf/ft**2)= 1480.37
 static density at compressor inlet(lbm/ft**3)= 0.04982
0 acoustic speed at compressor inlet(ft/s)=1156.55713
 axial velocity at compressor inlet(ft/s)= 625.29999
 mach number at compressor inlet= -0.63642
 streamtube area at compressor inlet(ft**2)= 0.24160
 flow coefficient at compressor inlet= 0.77736
1***** design point information ***** ***
0 ***** stage= 1 *****

0 total total static static static
 temp pressure temp pressure density
 0 rotor inlet 602.000 1944.000 554.852 1460.540 0.049
 rotor outlet 646.018 2437.776 582.467 1694.070 0.055
 0 axial absolute relative tan comp tan comp
 velocity velocity velocity of abs vel of rel vel
 0 rotor inlet 653.90002 728.27600 901.76440 320.62540 620.96191
 rotor outlet 632.00000 875.68225 762.34113 606.13159 329.61261
 0 rotor abs mach rel mach rel total rel total
 speed number number temp pressure
 0 rotor inlet 941.587 0.653 0.781 622.410 2185.063
 rotor outlet 935.744 0.741 0.645 630.648 5747.708
 0 abs flow rel flow streamtube flow
 angle angle area radius coefficient
 0 rotor inlet 26.12000 43.52000 0.33861 11.28000 0.54140
 rotor outlet 43.80309 25.61799 0.30958 11.21000 0.52327
 0 stage total pressure ratio at design point= 1.24800
 stage adiabatic efficiency at design point= 0.89109
 rotor total pressure ratio at design point= 1.25400
 rotor adiabatic efficiency at design point= 0.91200
 rotor total temperature ratio at design point= 1.07312
 **** design point information ****
 0 ***** stage= 2 *****
 0 total total static static static
 temp pressure temp pressure density
 0 rotor inlet 646.018 2426.112 606.280 1941.056 0.060
 rotor outlet 687.268 2991.396 632.514 2232.765 0.066
 0 axial absolute relative tan comp tan comp
 velocity velocity velocity of abs vel of rel vel
 0 rotor inlet 634.59998 694.17151 916.97321 281.34848 661.90845
 rotor outlet 606.50000 813.80762 725.84167 542.62378 405.64148
 0 rotor abs mach rel mach rel total rel total
 speed number number temp pressure
 0 rotor inlet 943.257 0.574 0.760 675.988 2845.161
 rotor outlet 948.265 0.661 0.589 676.086 6382.674
 0 abs flow rel flow streamtube flow
 angle angle area radius coefficient
 0 rotor inlet 23.91000 46.20665 0.29752 11.30000 0.53399
 rotor outlet 41.81838 33.97677 0.28323 11.36000 0.51034
 0 stage total pressure ratio at design point= 1.22700
 stage adiabatic efficiency at design point= 0.93777
 rotor total pressure ratio at design point= 1.23300
 rotor adiabatic efficiency at design point= 0.96200
 rotor total temperature ratio at design point= 1.06385
 **** design point information ****
 ***** overall performance at design point **** *****
 0 compressor inlet total temperature= 602.00
 0 compressor inlet total pressure= 1944.00
 0 corrected mass flow rate= 135.446
 0 overall total pressure ratio= 1.5313
 0 overall total temperature ratio= 1.1416

0 overall adiabatic efficiency=0.9102
 0 overall temperature rise= 85.268
 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
 bet1sr(i) 43.52 46.21
 bet2sr(i) 25.62 33.98
 aincsr(i) 0.82 0.61
 adevsr(i) -6.08 3.38
 bet1ss(i) 43.80 41.82
 bet2ss(i) 23.91 25.81 26.12
 aincss(i) 3.40 -2.13
 adevss(i) 6.91 7.96
 td(i) 602. 646.
 omegr(i) 0.063 0.026
 omegs(i) 0.016 0.019
 sitadr(i) .0399 .0174
 sitads(i) .0120 .0136
 deqr(i) 1.601 1.587
 deqs(i) 1.660 1.523
 1 fai=0.4500000
 xddin = 0.
 nhg main ws(1) tg(1) p(1) rhumid = 0.00000 602.000001944.00000 0.00001
 nhg main xv(1) xwt(1) xch4 = 0.00000 0.00000 0.00000
 0 vz at igv inlet = 543.50366 mach number = 0.46153
 i xwt watrgn
 1 0. 0.
 2 0. 0.
 3 0. 0.
 4 0. 0.
 5 0. 0.
 6 0. 0.
 7 0. 0.
 8 0. 0.
 9 0. 0.
 10 0. 0.
 xv(1) = 1.18659E-09
 watrgt = 0.
 0 istage=0 (igv)
 0 0.45000 543.50366 1.00000
 clear(1)= 1.00000E-03
 nhg main start calculations for stage 1
 d1 dwakem,w2= 0. 514.381
 d2 dwakem,rdelv1= 0. 10.00000
 d3 dwakem,rdelv2= 0. 0.
 ddave(n-2)(n)= 3 0. 472.146
 nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.00000 0.00000 0.00000
 0.00000 472.14648 0.00000 0.00000 0.00000
 nhg ds dl dlge dsll amlge amsll= 0.00000 472.14648 0.00000 0.00000 0.00000 0.00000
 nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 filmas(1)= 5.55582E-02
 ui = 23.5166

hhc = 0.750000
 htot = 7.50000E-04
 1 ***** initial flow coefficient= 0.450 (stage= 1) ****=
 0 stage total pressure ratio= 1.35248
 stage total temperature ratio= 1.10863
 stage adiabatic efficiency= 0.82645
 0 stage flow coefficient=0.305
 axial velocity= 368.37
 rotor speed=1207.79
 0 *rotor inlet* *rotor outlet* *stator outlet*
 total pressure 1944.0000 2636.5400 2629.2144
 static pressure 1805.3267 2192.1331 2450.7463
 total temperature(gas) 602.0000 667.3978 667.3978
 static temperature(gas) 589.4261 633.1794 654.1548
 static density(gas) 0.0574 0.0649 0.0702
 static density(mixture) 0.0574 0.0649 0.0702
 0 axial velocity 368.3688 336.4398 339.1703
 absolute velocity 389.0350 641.8840 399.3185
 relative velocity 895.7287 514.3813
 blade speed 941.5873 935.7442 943.2569
 tang. comp. of abs. vel. 125.1105 546.6473
 tang. comp. of rel. vel. 816.4768 389.0969
 acoustic speed 1189.7568 1253.3921 1253.3827
 absolute mach number 0.3270 0.5205 0.3186
 relative mach number 0.7529 0.4171
 0 flow coefficient 0.3050 0.2786 0.2854
 flow area 0.3386 0.3280 0.3007
 0 absolute flow angle 18.7592 58.3893 31.8565
 relative flow angle 65.7166 49.1511
 incidence 23.0166 17.9893
 deviation 17.4511 14.8565
 diffusion ratio 3.6653 2.6688
 momentum thickness 0.1314 0.0192
 omega (gas) 0.17564 0.01648
 omega (total) 0.17564 0.01648
 d1 dwakem,v3= 0. 399.318
 d2 dwakem,sdelv1= 0. 10.00000
 d3 dwakem,sdelv2= 0. 0.
 n,ddave(n-2)(n)= 4 0. 465.064
 nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.00000 0.00000 0.00000
 0.00000 465.06369 0.00000 0.00000 0.00000
 nhg ds dl dlge dsll amlge amsll= 0.00000 465.06369 0.00000 0.00000 0.00000 0.00000
 nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1 ***** initial flow coefficient= 0.450 (istage= 1)

 0 stage total pressure ratio= 1.35248
 stage total temperature ratio= 1.10863
 stage adiabatic efficiency= 0.82645
 stage 1 total ETA 0.82645del T 65.39777

```

0psi= 5.4154E-01 psi1= 4.4755E-01 loss= 9.3985E-02
0      **stage inlet**   **stage outlet**   **stage outlet**
          (before inter-    (after inter-
          stage adjust-    stage adjust-
          ment)        ment)

xv=     0.00000     0.00000     0.00000
xw=     0.00000     0.00000     0.00000
xww=    0.00000     0.00000     0.00000
xf=     0.00000     0.00000     0.00076
xwt=    0.00000     0.00000     0.00000
xair=   1.00000     1.00000     1.00000
xmetan= 0.00000     0.00000     0.00000
xgas=   1.00000     1.00000     1.00000
wmass=  0.00000     0.00000     0.00000
wwmass= 0.00000     0.00000     0.00000
fmmass= 0.07102     0.07102     0.05556
wtrmass= 0.00000     0.00000     0.00000
amass=  7.16060     7.16060     7.16060
chmass= 0.00000     0.00000     0.00000
vmass=  0.00000     0.00000     0.00000
gmass=  7.16060     7.16060     7.16060
tmass=  7.16060     7.16060     7.16060
ws=    0.00000     0.00000     0.00000
rhoa=  0.06054     0.06333     0.07015
rhom=  0.05453     0.06332     0.07013
rhog=  0.05741     0.06332     0.07013
tg=   602.00000    667.39777    667.39777
tw=   597.00000    597.00000    597.00000
tww=  597.00000    0.00000    597.00000
nhg: tragas, trawat = 1.10863 1.00000
p= 1944.00000 2636.54004 2629.21436
tb= 667.26837 0.00000 682.17615
tdew= 272.00754 274.47519 274.47519
writing to external plot files
clear( 2)= 1.00000E-03
nhg main start calculations for stage 2
d1 dwakem,w2= 0. 581.754
d2 dwakem,rdelv1= 0. 10.00000
d3 dwakem,rdelv2= 0. 0.
ddave(n-2)(n)= 5 0. 410.474
nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.00000 0.00000 0.00000
0.00000 410.47403 0.00000 0.00000 0.00000
nhg ds dl dlge dsll amlge amsll= 0.00000 410.47403 0.00000 0.00000 0.00000 0.00000
nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.00000 0.00000
0.00000 0.00000 0.00000 0.00000 0.00000
filmas( 2)= 5.71048E-02
ui = 272.208
hhc = 7.78868E-03
htot = 7.78868E-06
1 ***** initial flow coefficient= 0.450 (stage= 2 ) *****
0 stage total pressure ratio= 1.18858

```

stage total temperature ratio= 1.06192
 stage adiabatic efficiency= 0.81180
 0 stage flow coefficient=0.289
 axial velocity= 343.18
 rotor speed=1188.42

	rotor inlet	*rotor outlet*	*stator outlet*		
total pressure	2629.2144	3143.2776	3125.0408		
static pressure	2446.6165	2724.6399	2926.7351		
total temperature(gas)	667.3978	708.7259	708.7259		
static temperature(gas)	653.8803	680.5155	695.6439		
static density(gas)	0.0701	0.0750	0.0789		
static density(mixture)	0.0701	0.0750	0.0789		
0 axial velocity	343.1790	338.8469	322.4617		
absolute velocity	404.0382	583.7836	397.5429		
relative velocity	806.6497	581.7543			
blade speed	943.2569	948.2653	0.0000		
tang. comp. of abs. vel.	213.2488	475.3798			
tang. comp. of rel. vel.	730.0081	472.8856			
acoustic speed	1252.2930	1291.6169	1291.6661		
absolute mach number	0.3226	0.4570	0.3078		
relative mach number	0.6441	0.4554			
0 flow coefficient	0.2888	0.2851	0.2713		
flow area	0.2975	0.2816	0.2816		
0 absolute flow angle	31.8565	54.5190	35.7935		
relative flow angle	64.8216	54.3764			
incidence	19.2216	10.5690			
deviation	23.7764	17.9435			
diffusion ratio	3.9221	3.4434			
momentum thickness	0.0816	0.0371			
omega (gas)	0.13314	0.04356			
omega (total)	0.13314	0.04356			
d1 dwakem,v3=	0.	397.543			
d2 dwakem,sdelv1=	0.	10.00000			
d3 dwakem,sdelv2=	0.	0.			
n,ddave(n-2)(n)=	6	0.	420.337		
nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 =	0.00000	0.00000	0.00000	0.00000	
0.00000 420.33719	0.00000	0.00000	0.00000	0.00000	
nhg ds dl dlge dsll amlge amsll=	0.00000	420.33719	0.00000	0.00000	0.00000
nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 =	0.00000	0.00000	0.00000	0.00000	
0.00000 0.00000	0.00000	0.00000	0.00000	0.00000	
1 ***** initial flow coefficient= 0.450 (istage= 2)	*****	*****	*****	*****	
0 stage total pressure ratio=	1.18858				
stage total temperature ratio=	1.06192				
stage adiabatic efficiency=	0.81180				
stage 2 total ETA	0.81378del T	41.32812			
0psi= 8.8609E-01	psi1= 7.2108E-01	loss= 1.6501E-01			
0 **stage inlet**	**stage outlet**	**stage outlet**			
(before inter-	(after inter-				
stage adjust-	stage adjust-				

	ment)	ment)	
xv=	0.00000	0.00000	0.00000
xw=	0.00000	0.00000	0.00000
xww=	0.00000	0.00000	0.00000
xf=	0.00076	0.00076	0.00078
xwt=	0.00000	0.00000	0.00000
xair=	1.00000	1.00000	1.00000
xmetan=	0.00000	0.00000	0.00000
xgas=	1.00000	1.00000	1.00000
wmass=	0.00000	0.00000	0.00000
wwmass=	0.00000	0.00000	0.00000
fmmass=	0.05556	0.05556	0.05710
wtmass=	0.00000	0.00000	0.00000
amass=	7.16060	7.16060	7.16060
chmass=	0.00000	0.00000	0.00000
vmass=	0.00000	0.00000	0.00000
gmass=	7.16060	7.16060	7.16060
tmass=	7.16060	7.16060	7.16060
ws=	0.00000	0.00000	0.00000
rhoa=	0.07385	0.07516	0.07892
rhom=	0.05453	0.07515	0.07890
rhog=	0.07013	0.07515	0.07890
tg=	667.39777	708.72589	708.72589
tw=	597.00000	597.00000	597.00000
tww=	597.00000	0.00000	597.00000
nhg: tragas, trawat =	1.06192	1.00000	
p=	2629.21436	3143.27759	3125.04077
tb=	682.17615	0.00000	692.03601
tdew=	274.47519	268.01367	268.01367

writing to external plot files

***** overall performance *****

0 initial flow coefficient=0.450

0 corrected speed= 8879.0 1.000 fraction of design corrected speed

0 initial water content(small droplet)=0.000

initial water content(large droplet)=0.000

initial water content(total)=0.000

initial relative humidity= 0.0 per cent

initial methane content=0.000

0 compressor inlet total temperature= 602.00

0 compressor inlet total pressure= 1944.00

0 corrected mass flow rate of mixture= 120.29

0 corrected mass flow rate of gas phase 120.29

0 overall total pressure ratio= 1.6075

0 overall total temperature ratio=1.1773

0 overall adiabatic efficiency=0.8152

***** performance of fan,lpc,hpc *****

0 gas phase stagnation stagnation adiabatic

0 corrected pressure temperature efficiency

0 mass flow ratio ratio

0 fan 0.0000 0.0000 0.0000 0.0000

0 lpc 0.0000 0.0000 0.0000 0.0000

```

0 hpc 0.0000 0.0000 0.0000 0.0000
0psi= 9.1772E-01 psi1= 7.4815E-01 loss= 1.6957E-01
i= 55
1 fai=0.4500000
xddin = 4.00000E-02
nhg main ws(1) tg(1) p(1) rhumid = 0.01187 602.000001944.00000 100.00000
nhg main xv(1) xwt(1) xch4 = 0.01126 0.04000 0.00000
0 vz at igt inlet = 543.50366 mach number = 0.46995
i xwt watrgn
1 4.00000E-02 0.301641
2 4.00000E-02 0.301641
3 4.00000E-02 0.301641
4 4.00000E-02 0.301641
5 4.00000E-02 0.301641
6 4.00000E-02 0.301641
7 4.00000E-02 0.301641
8 4.00000E-02 0.301641
9 4.00000E-02 0.301641
10 4.00000E-02 0.301641
xv(1) = 1.12577E-02
watrgt = 3.01641
d0 dwakem,w2= 600.000 543.504
0 istage=0 (igt)
0 0.45000 543.50366 0.94874
clear( 1)= 1.00000E-03
nhg main start calculations for stage 1
d1 dwakem,w2= 0. 515.749
d2 dwakem,rdelv1= 600.000 18.9275
d3 dwakem,rdelv2= 433.842 0.
ddave(n-2)(n)= 3 600.000 0.
nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.14756 0.00000 0.03402
0.11354 0.00000 0.00000 0.00000 600.00000 433.84219
nhg ds dl dlge dsll amlge amsll= 0.00000 0.00000 472.14655 0.00000 0.14756 0.14756
nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.14756 0.00000
0.03402 0.11354 0.00000 472.14655 0.00000 600.00000 433.84219
filmas( 1)= 0.169656
ui = 23.5166
hhc = 0.750000
htot = 7.50000E-04
n,ddave(n-1)(n)= 3 600.000 472.147
n,ddave(n-1)(n)= 3 600.000 472.147
1 ***** initial flow coefficient= 0.450 (stage= 1 ) *****
0 stage total pressure ratio= 1.33462
stage total temperature ratio= 1.10833
stage adiabatic efficiency= 0.78831
0 stage flow coefficient=0.304
axial velocity= 367.58
rotor speed=1207.79

0 *rotor inlet* *rotor outlet* *stator outlet*
total pressure 1944.0000 2608.4819 2594.5100

```

static pressure 1801.3136 2148.7932 2409.4758
 total temperature(gas) 602.0000 667.2146 667.2146
 static temperature(gas) 589.0900 632.7929 653.9154
 static density(gas) 0.0569 0.0632 0.0686
 static density(mixture) 0.0593 0.0658 0.0714
 0 axial velocity 367.5780 341.7137 343.5442
 absolute velocity 388.1998 647.0368 402.8692
 relative velocity 895.6487 515.7485
 blade speed 941.5873 935.7442 943.2569
 tang. comp. of abs. vel. 124.8420 549.4436
 tang. comp. of rel. vel. 816.7454 386.3006
 acoustic speed 1168.8855 1211.4681 1230.6973
 absolute mach number 0.3321 0.5341 0.3274
 relative mach number 0.7662 0.4257
 0 flow coefficient 0.3043 0.2829 0.2891
 flow area 0.3386 0.3280 0.3007
 0 absolute flow angle 18.7592 58.1214 31.4886
 relative flow angle 65.7698 48.5047
 incidence 23.0698 17.7214
 deviation 16.8047 14.4886
 diffusion ratio 3.6611 2.6438
 momentum thickness 0.1380 0.0191
 omega (gas) 0.17676 0.01646
 omega (total) 0.20246 0.03734
 d1 dwakem,v3= 600.000 402.869
 d2 dwakem,sdelv1= 600.000 18.9275
 d3 dwakem,sdelv2= 400.076 0.
 n,ddave(n-2)(n)= 4 600.000 0.
 nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.08616 0.12958 0.06140 0.00584
 0.01213 0.00000 0.00000 20.00000 600.00000 400.07565
 nhg ds dl dlge dsll amlge amsll= 0.00000 0.00000 465.06369 4.43073 0.01798 0.27715
 nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.08616 0.12958 0.06140
 0.00584 0.01213 4.43073 465.06369 20.00000 600.00000 400.07565
 n,ddave(n-1)(n)= 4 472.147 465.064
 n,ddave(n-1)(n)= 4 472.147 465.064
 xnp,tg(3),p(3)= 3.20075E+10 667.135 2594.51
 1 ***** initial flow coefficient= 0.450 (istage= 1)

 0 stage total pressure ratio= 1.33462
 stage total temperature ratio= 1.10820
 stage adiabatic efficiency= 0.78907
 stage 1 total ETA 0.78907del T 65.13525
 Opsi= 5.4574E-01 psi1= 4.3063E-01 loss= 1.1511E-01
 0 **stage inlet** **stage outlet** **stage outlet**
 (before inter- (after inter-
 stage adjust- stage adjust-
 ment) (ment)
 xv= 0.01126 0.01126 0.01308
 xw= 0.00000 0.00000 0.00000
 xww= 0.04000 0.04000 0.03818
 xf= 0.00007 0.00007 0.00225

xwt=	0.04000	0.04000	0.03818
xair=	0.94874	0.94874	0.94874
xmetan=	0.00000	0.00000	0.00000
xgas=	0.96000	0.96000	0.96182
wmass=	0.00000	0.00000	0.00000
wwmass=	0.29512	0.29512	0.28170
fmmass=	0.05556	0.05556	0.16966
wtmass=	0.29512	0.29512	0.28170
amass=	6.99987	6.99987	6.99987
chmass=	0.00000	0.00000	0.00000
vmass=	0.08306	0.08306	0.09648
gmass=	7.08293	7.08293	7.09635
tmass=	7.37806	7.37806	7.37806
ws=	0.01187	0.01187	0.01378
rhoa=	0.06054	0.06216	0.06484
rhom=	0.05619	0.06428	0.07118
rhog=	0.05691	0.06171	0.06847
tg=	602.00000	667.21460	667.13525
tw=	597.00000	597.00000	597.00000
tww=	597.00000	597.00000	597.44580
nhg: tragas, trawat =	1.10820	1.00075	
p=	1944.00000	2608.48193	2594.51001
tb=	667.26837	0.00000	681.50610
tdew=	518.09930	526.80371	531.09418
writing to external plot files			
clear(2)=	1.00000E-03		
nhg main start calculations for stage 2			
d1 dwakem,w2=	0.	585.055	
d2 dwakem,rdelv1=	600.000	18.8394	
d3 dwakem,rdelv2=	363.792	0.	
ddave(n-2)(n)=	5	472.147	0.
nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 =	0.00000	0.14085	0.00000 0.02855
0.11230 0.00000 0.00000 0.00000 600.00000 363.79233			
nhg ds dl dlge dsll amlge amsll=	0.00000	0.00000	411.66669 0.00000 0.14085 0.14085
nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 =	0.00000	0.14085	0.00000
0.02855 0.11230 0.00000 411.66669 0.00000 600.00000 363.79233			
filmas(2) =	0.476775		
ui =	30.7086		
hhc =	0.718209		
htot =	7.18209E-04		
n,ddave(n-1)(n)=	5 465.064	411.667	
n,ddave(n-1)(n)=	5 465.064	411.667	
1 ***** initial flow coefficient= 0.450 (stage= 2) *****			
0 stage total pressure ratio=	1.17666		
stage total temperature ratio=	1.06177		
stage adiabatic efficiency=	0.76247		
0 stage flow coefficient=0.293			
axial velocity=	348.37		
rotor speed=	1188.42		

0 *rotor inlet* *rotor outlet* *stator outlet*

total pressure 2594.5100 3081.0574 3052.8523
 static pressure 2404.7615 2649.0469 2846.5596
 total temperature(gas) 667.1353 708.3432 708.3432
 static temperature(gas) 652.9359 679.7630 695.0020
 static density(gas) 0.0685 0.0724 0.0761
 static density(mixture) 0.0712 0.0753 0.0792
 0 axial velocity 348.3744 347.8579 330.9785
 absolute velocity 408.5336 591.0604 404.3733
 relative velocity 808.7470 585.0549
 blade speed 943.2569 948.2653 0.0000
 tang. comp. of abs. vel. 213.3892 477.8569
 tang. comp. of rel. vel. 729.8677 470.4084
 acoustic speed 1231.5189 1256.5637 1269.8992
 absolute mach number 0.3317 0.4704 0.3184
 relative mach number 0.6567 0.4656
 0 flow coefficient 0.2931 0.2927 0.2785
 flow area 0.2975 0.2816 0.2816
 0 absolute flow angle 31.4886 53.9471 35.0653
 relative flow angle 64.4843 53.5178
 incidence 18.8843 9.9971
 deviation 22.9178 17.2153
 diffusion ratio 3.8691 3.3655
 momentum thickness 0.0829 0.0355
 omega (gas) 0.13046 0.04166
 omega (total) 0.15583 0.06932
 d1 dwakem,v3= 600.000 404.373
 d2 dwakem,sdelv1= 600.000 18.8394
 d3 dwakem,sdelv2= 342.674 0.
 n,ddave(n-2)(n)= 6 465.064 0.
 nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.09618 0.12391 0.04467 0.00517
 0.01177 0.00000 0.00000 20.00000 600.00000 342.67392
 nhg ds dl dlge dsll amlge amsll= 0.00000 0.00000 421.20795 3.37468 0.01694 0.26476
 nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.09618 0.12391 0.04467
 0.00517 0.01177 3.37468 421.20795 20.00000 600.00000 342.67392
 n,dave(n-1)(n)= 6 0. 3.37468
 n,ddave(n-1)(n)= 6 411.667 421.208
 n,dave(n-1)(n)= 6 0. 3.37468
 n,ddave(n-1)(n)= 6 411.667 421.208
 xnp,tg(3),p(3)= 3.20075E+10 708.218 3052.85
 xnp,tg(3),p(3)= 3.05521E+10 708.218 3052.85
 1 ***** initial flow coefficient= 0.450 (istage= 2)

 0 stage total pressure ratio= 1.17666
 stage total temperature ratio= 1.06158
 stage adiabatic efficiency= 0.76428
 stage 2 total ETA 0.77133del T 41.08319
 Opsi= 8.9614E-01 psi1= 6.9122E-01 loss= 2.0492E-01
 0 **stage inlet** **stage outlet** **stage outlet**
 (before inter- (after inter-
 stage adjust- stage adjust-
 ment) ment)

xv=	0.01308	0.01308	0.01789
xw=	0.00000	0.00000	0.00000
xww=	0.03818	0.03818	0.03337
xf=	0.00225	0.00225	0.00632
xwt=	0.03818	0.03818	0.03337
xair=	0.94874	0.94874	0.94874
xmetan=	0.00000	0.00000	0.00000
xgas=	0.96182	0.96182	0.96663
wmass=	0.00000	0.00000	0.00000
wwmass=	0.28170	0.28170	0.24623
fmmass=	0.16966	0.16966	0.47678
wtmass=	0.28170	0.28170	0.24623
amass=	6.99987	6.99987	6.99987
chmass=	0.00000	0.00000	0.00000
vmass=	0.09648	0.09648	0.13196
gmass=	7.09635	7.09635	7.13183
tmass=	7.37806	7.37806	7.37806
ws=	0.01378	0.01378	0.01885
rhoa=	0.07291	0.07330	0.07230
rhom=	0.05619	0.07557	0.07862
rhog=	0.06847	0.07269	0.07600
tg=	667.13525	708.34320	708.21844
tw=	597.00000	597.00000	597.00000
tw=	597.44580	597.44580	598.18591
nhg: tragas, trawat =	1.06158	1.00124	
p=	2594.51001	3081.05737	3052.85229
tb=	681.50610	0.00000	690.75311
tdew=	531.09418	530.05609	539.78143

writing to external plot files

***** overall performance *****

0 initial flow coefficient=0.450

0 corrected speed= 8879.0 1.000 fraction of design corrected speed

0 initial water content(small droplet)=0.000

initial water content(large droplet)=0.040

initial water content(total)=0.040

initial relative humidity=100.0 per cent

initial methane content=0.000

0 compressor inlet total temperature= 602.00

0 compressor inlet total pressure= 1944.00

0 corrected mass flow rate of mixture= 123.94

0 corrected mass flow rate of gas phase 118.99

0 overall total pressure ratio= 1.5704

0 overall total temperature ratio=1.1764

0 overall adiabatic efficiency=0.7729

***** performance of fan,lpc,hpc *****

0 gas phase stagnation stagnation adiabatic

0 corrected pressure temperature efficiency

0 mass flow ratio ratio

0 fan 0.0000 0.0000 0.0000 0.0000

0 lpc 0.0000 0.0000 0.0000 0.0000

0 hpc 0.0000 0.0000 0.0000 0.0000

0psi= 9.1336E-01 psi1= 7.0596E-01 loss= 2.0739E-01
i= 55
Number of loops = 100
total mass = 0.378182
0psi= 9.1336E-01 psi1= 7.0596E-01 loss= 2.0739E-01
i= 55
gemach = 0.273104

APPENDIX E

File 4: blheat2.out

Compressor flow adiabatic

initial clearance at ref.temp. (R)= 518.700

stage 1 : clearance[in]= 7.00092E-03

stage 2 : clearance[in]= 6.99997E-03

initial steady thermal node and blade clearance

node no. Node temp.(K):

1 3.0957E+02 2 3.1387E+02 3 3.1467E+02 4 3.0996E+02 5 3.1591E+02 6
3.1536E+02 7 3.1469E+02 8 3.2398E+02

9 3.1757E+02 10 3.2224E+02 11 3.2962E+02 12 3.4331E+02 13 3.3565E+02 14
3.3425E+02 15 3.5303E+02 16 3.2337E+02

17 3.2321E+02 18 3.5220E+02 19 3.2239E+02

stage 1 : clearance[in]= 4.82655E-03

stage 2 : clearance[in]= 1.40285E-03

jsweep= 1

i,T(K):

1 3.0992E+02 2 3.1436E+02 3 3.1634E+02 4 3.1852E+02 5 3.3901E+02 6
3.1566E+02 7 3.1471E+02 8 3.2444E+02

9 3.3160E+02 10 3.2711E+02 11 3.5678E+02 12 3.6971E+02 13 3.3610E+02 14
3.3426E+02 15 3.5800E+02 16 3.3190E+02

17 3.3556E+02 18 3.7663E+02 19 3.8593E+02

stage 1 : clearance[in]= 3.95489E-03

stage 2 : clearance[in]= 2.67029E-05

jsweep= 10

stage 1 : clearance[in]= 3.89576E-03

stage 2 : clearance[in]= -3.91006E-05

jsweep= 20

stage 1 : clearance[in]= 3.93009E-03

stage 2 : clearance[in]= -6.67572E-06

jsweep= 30

stage 1 : clearance[in]= 3.89862E-03

stage 2 : clearance[in]= -3.71933E-05

jsweep= 40

stage 1 : clearance[in]= 3.92628E-03

stage 2 : clearance[in]= -1.23978E-05

jsweep= 50

stage 1 : clearance[in]= 3.89957E-03

stage 2 : clearance[in]= -3.71933E-05

jsweep= 60

stage 1 : clearance[in]= 3.92246E-03
stage 2 : clearance[in]= -1.62125E-05

jsweep= 70
stage 1 : clearance[in]= 3.89957E-03
stage 2 : clearance[in]= -3.71933E-05

jsweep= 80
stage 1 : clearance[in]= 3.91865E-03
stage 2 : clearance[in]= -2.00272E-05

jsweep= 90
stage 1 : clearance[in]= 3.90053E-03
stage 2 : clearance[in]= -3.71933E-05

jsweep= 100
i,T(K):
1 3.1010E+02 2 3.1475E+02 3 3.1708E+02 4 3.1948E+02 5 3.3932E+02 6
3.1580E+02 7 3.1473E+02 8 3.2468E+02
9 3.3161E+02 10 3.2908E+02 11 3.5725E+02 12 3.7011E+02 13 3.3636E+02 14
3.3428E+02 15 3.6021E+02 16 3.3192E+02
17 3.4101E+02 18 3.7951E+02 19 3.8587E+02
stage 1 : clearance[in]= 3.91674E-03
stage 2 : clearance[in]= -2.38419E-05

APPENDIX E

File 5: case3.out

Input Data - Wet Case 1
Compressor flow adiabatic
icase= 4

phi design = 0.7773584

inlet phi =0.4500000
0psi= 9.1772E-01 psi1= 7.4815E-01 loss= 1.6957E-01
jsweep= 100

MEAN

fraction of design speed = 1.00000
>>>>>>> loop number 2 <<<<<<

igv area= 0.241601
nhg number of streamlines = 10.22089
1 ***** input data

heat transfer after rotor and stator version
0 number of stages= 2 (fan 0, lpc 2, hpc 0)
performance at mean
0 vapor is centrifuged
0 large droplets in rotor free stream are not centrifuged

stage	1	2	3
rrhub(i)	6.95	7.64	
rc(i)	2.170	2.436	
rblade(i)	36.00	26.00	
stager(i)	37.20	38.10	
stages(i)	28.70	30.90	31.80
srhub(i)	7.35	8.10	8.73
sc(i)	1.880	1.665	1.484
sblade(i)	36.00	40.00	46.00
sigumr(i)	1.106	0.891	
sigums(i)	0.958	0.929	0.940
bet2ss(i)	23.91	25.81	26.12
gapr(i)	0.577	0.728	
gaps(i)	0.790	0.860	
rrtip(i)	14.47	14.24	
srtip(i)	14.37	14.12	13.91
rt(i)	14.47	14.24	
rm(i)	11.28	11.30	
rh(i)	6.95	7.64	
st(i)	14.37	14.12	
sm(i)	11.21	11.36	
sh(i)	7.35	8.10	
block(i)	0.985	0.950	
blocks(i)	0.945	0.955	0.965
bet1mr(i)	42.70	45.60	
bet2mr(i)	31.70	30.60	

bet1ms(i) 40.40 43.95 46.25
 bet2ms(i) 17.00 17.85 17.35
 pr12d(i) 1.254 1.233
 pr13d(i) 1.248 1.227
 etard(i) 0.912 0.962
 dvz1(i) 653.9 634.6 625.3
 dvz2(i) 632.0 606.5 591.6
 dvz3(i) 623.2 610.3
 ak1(i) 2.300 1.460
 ak2(i) 0.090 0.090
 ak3(i) 1.000 1.500
 1 ***** input data *****
 0 fnf(fraction of design corrected speed)=1.000
 0 xdin(initial water content of small droplet)=0.000
 xddin(initial water content of large droplet)=1.000
 rhumid(initial relative humidity)= 0.00 per cent
 xch4(initial methane content)=0.000
 0 t0g(compressor inlet total temperature of gas)= 602.00
 t0w(compressor inlet temperature of droplet)= 597.00
 p0(compressor inlet total pressure)=1944.00
 0 din(initial droplet diameter of small droplet)= 20.0
 ddin(initial droplet diameter of large droplet)= 600.0
 0 fnd(design rotational speed)= 8879.0
 0 dsmass(design stream mass flow rate)= 11.3000
 0 bypass ratio = 0.0000
 0 compressor inlet total temperature(gas phase) 602.00 r
 0 compressor inlet total pressure=1944.00 lb/ft**2
 0 preb(percent of water that rebound after impingement)= 50.0 percent
 0 rotor speed= 9565.4 rpm
 0 corrected rotor speed= 8879.0 rpm(100.0 per cent of design corrected speed)
 0 molecular weight of air= 28.9700
 0 maximum diameter of small droplets= 300.0 microns
 0 rotor corrected speed at design point= 8879.0
 rotor corrected speed of lpc at design point= 8879.0
 rotor corrected speed of hpc at the design point= 8879.0
 design flow coefficient at inlet = 0.777358
 1***** design point information *****
 0 ***** compressor inlet *****
 0 total temperature at compressor inlet(R)= 602.00000
 total pressure at compressor inlet(lbf/ft**2)= 1944.00
 static temperature at compressor inlet(R)= 556.98975
 static pressure at compressor inlet(lbf/ft**2)= 1480.37
 static density at compressor inlet(lbm/ft**3)= 0.04982
 0 acoustic speed at compressor inlet(ft/s)=1156.55713
 axial velocity at compressor inlet(ft/s)= 625.29999
 mach number at compressor inlet= -0.63642
 streamtube area at compressor inlet(ft**2)= 0.24160
 flow coefficient at compressor inlet= 0.77736
 1***** design point information *****
 0 ***** stage= 1 *****

0 total total static static static
 temp pressure temp pressure density
 0 rotor inlet 602.000 1944.000 554.852 1460.540 0.049
 rotor outlet 646.018 2437.776 582.467 1694.070 0.055
 0 axial absolute relative tan comp tan comp
 velocity velocity velocity of abs vel of rel vel
 0 rotor inlet 653.90002 728.27600 901.76440 320.62540 620.96191
 rotor outlet 632.00000 875.68225 762.34113 606.13159 329.61261
 0 rotor abs mach rel mach rel total rel total
 speed number number temp pressure
 0 rotor inlet 941.587 0.653 0.781 622.410 2185.063
 rotor outlet 935.744 0.741 0.645 630.648 5747.708
 0 abs flow rel flow streamtube flow
 angle angle area radius coefficient
 0 rotor inlet 26.12000 43.52000 0.33861 11.28000 0.54140
 rotor outlet 43.80309 25.61799 0.30958 11.21000 0.52327
 0 stage total pressure ratio at design point= 1.24800
 stage adiabatic efficiency at design point= 0.89109
 rotor total pressure ratio at design point= 1.25400
 rotor adiabatic efficiency at design point= 0.91200
 rotor total temperature ratio at design point= 1.07312
 1***** design point information *****
 0 ***** stage= 2 *****
 0 total total static static static
 temp pressure temp pressure density
 0 rotor inlet 646.018 2426.112 606.280 1941.056 0.060
 rotor outlet 687.268 2991.396 632.514 2232.765 0.066
 0 axial absolute relative tan comp tan comp
 velocity velocity velocity of abs vel of rel vel
 0 rotor inlet 634.59998 694.17151 916.97321 281.34848 661.90845
 rotor outlet 606.50000 813.80762 725.84167 542.62378 405.64148
 0 rotor abs mach rel mach rel total rel total
 speed number number temp pressure
 0 rotor inlet 943.257 0.574 0.760 675.988 2845.161
 rotor outlet 948.265 0.661 0.589 676.086 6382.674
 0 abs flow rel flow streamtube flow
 angle angle area radius coefficient
 0 rotor inlet 23.91000 46.20665 0.29752 11.30000 0.53399
 rotor outlet 41.81838 33.97677 0.28323 11.36000 0.51034
 0 stage total pressure ratio at design point= 1.22700
 stage adiabatic efficiency at design point= 0.93777
 rotor total pressure ratio at design point= 1.23300
 rotor adiabatic efficiency at design point= 0.96200
 rotor total temperature ratio at design point= 1.06385
 1***** design point information *****
 0***** overall performance at design point **** *****
 0 compressor inlet total temperature= 602.00
 0 compressor inlet total pressure= 1944.00
 0 corrected mass flow rate= 135.446
 0 overall total pressure ratio= 1.5313
 0 overall total temperature ratio= 1.1416

0 overall adiabatic efficiency=0.9102
 0 overall temperature rise= 85.268
 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
 bet1sr(i) 43.52 46.21
 bet2sr(i) 25.62 33.98
 aincsr(i) 0.82 0.61
 adevsr(i) -6.08 3.38
 bet1ss(i) 43.80 41.82
 bet2ss(i) 23.91 25.81 26.12
 aincss(i) 3.40 -2.13
 adevss(i) 6.91 7.96
 td(i) 602. 646.
 omegr(i) 0.063 0.026
 omegs(i) 0.016 0.019
 sitadr(i) .0399 .0174
 sitads(i) .0120 .0136
 deqr(i) 1.601 1.587
 deqs(i) 1.660 1.523
 1 fai=0.4500000
 xddin = 0.
 nhg main ws(1) tg(1) p(1) rhumid = 0.00000 602.000001944.00000 0.00001
 nhg main xv(1) xwt(1) xch4 = 0.00000 0.00000 0.00000
 0 vz at igt inlet = 543.50366 mach number = 0.46153
 i xwt watrgn
 1 0. 0.
 2 0. 0.
 3 0. 0.
 4 0. 0.
 5 0. 0.
 6 0. 0.
 7 0. 0.
 8 0. 0.
 9 0. 0.
 10 0. 0.
 xv(1) = 1.18659E-09
 watrgt = 0.
 0 istage=0 (igt)
 0 0.45000 543.50366 1.00000
 clear(1)= 1.00000E-03
 nhg main start calculations for stage 1
 d1 dwakem,w2= 0. 514.381
 d2 dwakem,rdelv1= 0. 10.00000
 d3 dwakem,rdelv2= 0. 0.
 ddave(n-2)(n)= 3 0. 472.146
 nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.00000 0.00000 0.00000
 0.00000 472.14648 0.00000 0.00000 0.00000 0.00000
 nhg ds dl dlge dsll amsll= 0.00000 472.14648 0.00000 0.00000 0.00000 0.00000
 nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 filmas(1)= 5.55582E-02
 ui = 23.5166

hhc = 0.750000
 htotl = 7.50000E-04
 1 ***** initial flow coefficient= 0.450 (stage= 1) ****
 0 stage total pressure ratio= 1.35248
 stage total temperature ratio= 1.10863
 stage adiabatic efficiency= 0.82645
 0 stage flow coefficient=0.305
 axial velocity= 368.37
 rotor speed=1207.79
 0 *rotor inlet* *rotor outlet* *stator outlet*
 total pressure 1944.0000 2636.5400 2629.2144
 static pressure 1805.3267 2192.1331 2450.7463
 total temperature(gas) 602.0000 667.3978 667.3978
 static temperature(gas) 589.4261 633.1794 654.1548
 static density(gas) 0.0574 0.0649 0.0702
 static density(mixture) 0.0574 0.0649 0.0702
 0 axial velocity 368.3688 336.4398 339.1703
 absolute velocity 389.0350 641.8840 399.3185
 relative velocity 895.7287 514.3813
 blade speed 941.5873 935.7442 943.2569
 tang. comp. of abs. vel. 125.1105 546.6473
 tang. comp. of rel. vel. 816.4768 389.0969
 acoustic speed 1189.7568 1253.3921 1253.3827
 absolute mach number 0.3270 0.5205 0.3186
 relative mach number 0.7529 0.4171
 0 flow coefficient 0.3050 0.2786 0.2854
 flow area 0.3386 0.3280 0.3007
 0 absolute flow angle 18.7592 58.3893 31.8565
 relative flow angle 65.7166 49.1511
 incidence 23.0166 17.9893
 deviation 17.4511 14.8565
 diffusion ratio 3.6653 2.6688
 momentum thickness 0.1314 0.0192
 omega (gas) 0.17564 0.01648
 omega (total) 0.17564 0.01648
 d1 dwakem,v3= 0. 399.318
 d2 dwakem,sdelv1= 0. 10.00000
 d3 dwakem,sdelv2= 0. 0.
 n,ddave(n-2)(n)= 4 0. 465.064
 nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.00000 0.00000 0.00000
 0.00000 465.06369 0.00000 0.00000 0.00000
 nhg ds dl dlge dsll amlge amsll= 0.00000 465.06369 0.00000 0.00000 0.00000 0.00000
 nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.00000 0.00000
 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
 1 ***** initial flow coefficient= 0.450 (istage= 1)

 0 stage total pressure ratio= 1.35248
 stage total temperature ratio= 1.10863
 stage adiabatic efficiency= 0.82645
 stage 1 total ETA 0.82645del T 65.39777

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Opsi= 5.4154E-01 psi1= 4.4755E-01 loss= 9.3985E-02
0      **stage inlet**   **stage outlet**   **stage outlet***
               (before inter-   (after inter-
               stage adjust-   stage adjust-
               ment)         ment)

xv=    0.00000    0.00000    0.00000
xw=    0.00000    0.00000    0.00000
xww=   0.00000    0.00000    0.00000
xf=    0.00000    0.00000    0.00076
xwt=   0.00000    0.00000    0.00000
xair=  1.00000    1.00000    1.00000
xmetan= 0.00000    0.00000    0.00000
xgas=  1.00000    1.00000    1.00000
wmass= 0.00000    0.00000    0.00000
wwmass= 0.00000    0.00000    0.00000
fmmass= 0.07102    0.07102    0.05556
wtmass= 0.00000    0.00000    0.00000
amass= 7.16060    7.16060    7.16060
chmass= 0.00000    0.00000    0.00000
vmass= 0.00000    0.00000    0.00000
gmass= 7.16060    7.16060    7.16060
tmass= 7.16060    7.16060    7.16060
ws=    0.00000    0.00000    0.00000
rhoa=  0.06054    0.06333    0.07015
rhom=  0.05453    0.06332    0.07013
rhog=  0.05741    0.06332    0.07013
tg=    602.00000   667.39777   667.39777
tw=    597.00000   597.00000   597.00000
tww=   597.00000   0.00000    597.00000
nhg: tragas, trawat = 1.10863 1.00000
p=    1944.00000   2636.54004   2629.21436
tb=   667.26837   0.00000    682.17615
tdew= 272.00754   274.47519   274.47519
writing to external plot files
clear( 2)= 1.00000E-03
nhg main start calculations for stage 2
d1 dwakem,w2= 0. 581.754
d2 dwakem,rdelv1= 0. 10.00000
d3 dwakem,rdelv2= 0. 0.
ddave(n-2)(n)= 5 0. 410.474
nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.00000 0.00000 0.00000
0.00000 410.47403 0.00000 0.00000 0.00000 0.00000
nhg ds dl dlge dsll amlge amsll= 0.00000 410.47403 0.00000 0.00000 0.00000 0.00000
nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.00000 0.00000
0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
filmas( 2)= 5.71048E-02
ui = 272.208
hhc = 7.78868E-03
htot = 7.78868E-06
1 ***** initial flow coefficient= 0.450 (stage= 2 ) *****
0 stage total pressure ratio= 1.18858

```

stage total temperature ratio= 1.06192
 stage adiabatic efficiency= 0.81180
 0 stage flow coefficient=0.289
 axial velocity= 343.18
 rotor speed=1188.42

0	*rotor inlet*	*rotor outlet*	*stator outlet*
total pressure	2629.2144	3143.2776	3125.0408
static pressure	2446.6165	2724.6399	2926.7351
total temperature(gas)	667.3978	708.7259	708.7259
static temperature(gas)	653.8803	680.5155	695.6439
static density(gas)	0.0701	0.0750	0.0789
static density(mixture)	0.0701	0.0750	0.0789
0 axial velocity	343.1790	338.8469	322.4617
absolute velocity	404.0382	583.7836	397.5429
relative velocity	806.6497	581.7543	
blade speed	943.2569	948.2653	0.0000
tang. comp. of abs. vel.	213.2488	475.3798	
tang. comp. of rel. vel.	730.0081	472.8856	
acoustic speed	1252.2930	1291.6169	1291.6661
absolute mach number	0.3226	0.4570	0.3078
relative mach number	0.6441	0.4554	
0 flow coefficient	0.2888	0.2851	0.2713
flow area	0.2975	0.2816	0.2816
0 absolute flow angle	31.8565	54.5190	35.7935
relative flow angle	64.8216	54.3764	
incidence	19.2216	10.5690	
deviation	23.7764	17.9435	
diffusion ratio	3.9221	3.4434	
momentum thickness		0.0816	0.0371
omega (gas)		0.13314	0.04356
omega (total)		0.13314	0.04356
d1 dwakem,v3=	0.	397.543	
d2 dwakem,sdelv1=	0.	10.00000	
d3 dwakem,sdelv2=	0.	0.	
n,ddave(n-2)(n)=	6	0.	420.337
nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 =	0.00000	0.00000	0.00000 0.00000
0.00000 420.33719	0.00000	0.00000	0.00000 0.00000
nhg ds dl dlge dsl amlg amsll=	0.00000	420.33719	0.00000 0.00000 0.00000 0.00000
nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 =	0.00000	0.00000	0.00000 0.00000
0.00000 0.00000	0.00000	0.00000	0.00000 0.00000
1 ***** initial flow coefficient= 0.450 (istage= 2)	*****		
0 stage total pressure ratio=	1.18858		
stage total temperature ratio=	1.06192		
stage adiabatic efficiency=	0.81180		
stage 2 total ETA	0.81378del T	41.32812	
Opsi= 8.8609E-01	psi1= 7.2108E-01	loss= 1.6501E-01	
0 **stage inlet**	**stage outlet**	**stage outlet**	
(before inter-	(after inter-		
stage adjust-	stage adjust-		

	ment)	ment)	
xv=	0.00000	0.00000	0.00000
xw=	0.00000	0.00000	0.00000
xww=	0.00000	0.00000	0.00000
xf=	0.00076	0.00076	0.00078
xwt=	0.00000	0.00000	0.00000
xair=	1.00000	1.00000	1.00000
xmetan=	0.00000	0.00000	0.00000
xgas=	1.00000	1.00000	1.00000
wmass=	0.00000	0.00000	0.00000
wwmass=	0.00000	0.00000	0.00000
fmmass=	0.05556	0.05556	0.05710
wtmass=	0.00000	0.00000	0.00000
amass=	7.16060	7.16060	7.16060
chmass=	0.00000	0.00000	0.00000
vmass=	0.00000	0.00000	0.00000
gmass=	7.16060	7.16060	7.16060
tmass=	7.16060	7.16060	7.16060
ws=	0.00000	0.00000	0.00000
rhoa=	0.07385	0.07516	0.07892
rhom=	0.05453	0.07515	0.07890
rhog=	0.07013	0.07515	0.07890
tg=	667.39777	708.72589	708.72589
tw=	597.00000	597.00000	597.00000
tw=	597.00000	0.00000	597.00000
nhg: tragas, trawat =	1.06192	1.00000	
p=	2629.21436	3143.27759	3125.04077
tb=	682.17615	0.00000	692.03601
tdew=	274.47519	268.01367	268.01367

writing to external plot files

***** overall performance *****

0 initial flow coefficient=0.450

0 corrected speed= 8879.0 1.000 fraction of design corrected speed

0 initial water content(small droplet)=0.000

initial water content(large droplet)=0.000

initial water content(total)=0.000

initial relative humidity= 0.0 per cent

initial methane content=0.000

0 compressor inlet total temperature= 602.00

0 compressor inlet total pressure= 1944.00

0 corrected mass flow rate of mixture= 120.29

0 corrected mass flow rate of gas phase 120.29

0 overall total pressure ratio= 1.6075

0 overall total temperature ratio=1.1773

0 overall adiabatic efficiency=0.8152

***** performance of fan,lpc,hpc *****

0 gas phase stagnation stagnation adiabatic

0 corrected pressure temperature efficiency

0 mass flow ratio ratio

0 fan 0.0000 0.0000 0.0000 0.0000

0 lpc 0.0000 0.0000 0.0000 0.0000

0 hpc 0.0000 0.0000 0.0000 0.0000
 0psi= 9.1772E-01 psil= 7.4815E-01 loss= 1.6957E-01
 i= 55
 1 fai=0.4500000
 xddin = 4.00000E-02
 nhg main ws(1) tg(1) p(1) rhumid = 0.01187 602.000001944.00000 100.00000
 nhg main xv(1) xwt(1) xch4 = 0.01126 0.04000 0.00000
 0 vz at igv inlet = 543.50366 mach number = 0.46995
 i xwt watrgn
 1 4.00000E-02 0.301641
 2 4.00000E-02 0.301641
 3 4.00000E-02 0.301641
 4 4.00000E-02 0.301641
 5 4.00000E-02 0.301641
 6 4.00000E-02 0.301641
 7 4.00000E-02 0.301641
 8 4.00000E-02 0.301641
 9 4.00000E-02 0.301641
 10 4.00000E-02 0.301641
 xv(1) = 1.12577E-02
 watrgt = 3.01641
 d0 dwakem,w2= 600.000 543.504
 0 istage=0 (igv)
 0 0.45000 543.50366 0.94874
 clear(1)= 1.00000E-03
 nhg main start calculations for stage 1
 d1 dwakem,w2= 0. 515.749
 d2 dwakem,rdelv1= 600.000 18.9275
 d3 dwakem,rdelv2= 433.842 0.
 ddave(n-2)(n)= 3 600.000 0.
 nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.00000 0.14756 0.00000 0.03402
 0.11354 0.00000 0.00000 0.00000 600.00000 433.84219
 nhg ds dl dlge dsll amlge amsll= 0.00000 0.00000 472.14655 0.00000 0.14756 0.14756
 nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.00000 0.14756 0.00000
 0.03402 0.11354 0.00000 472.14655 0.00000 600.00000 433.84219
 filmas(1)= 0.169656
 ui = 23.5166
 hhc = 0.750000
 htotl = 7.50000E-04
 n,ddave(n-1)(n)= 3 600.000 472.147
 n,ddave(n-1)(n)= 3 600.000 472.147
 1 ***** initial flow coefficient= 0.450 (stage= 1) *****
 0 stage total pressure ratio= 1.33462
 stage total temperature ratio= 1.10833
 stage adiabatic efficiency= 0.78831
 0 stage flow coefficient=0.304
 axial velocity= 367.58
 rotor speed=1207.79
 0 *rotor inlet* *rotor outlet* *stator outlet*
 total pressure 1944.0000 2608.4819 2594.5100

static pressure 1801.3136 2148.7932 2409.4758
 total temperature(gas) 602.0000 667.2146 667.2146
 static temperature(gas) 589.0900 632.7929 653.9154
 static density(gas) 0.0569 0.0632 0.0686
 static density(mixture) 0.0593 0.0658 0.0714
 0 axial velocity 367.5780 341.7137 343.5442
 absolute velocity 388.1998 647.0368 402.8692
 relative velocity 895.6487 515.7485
 blade speed 941.5873 935.7442 943.2569
 tang. comp. of abs. vel. 124.8420 549.4436
 tang. comp. of rel. vel. 816.7454 386.3006
 acoustic speed 1168.8855 1211.4681 1230.6973
 absolute mach number 0.3321 0.5341 0.3274
 relative mach number 0.7662 0.4257
 0 flow coefficient 0.3043 0.2829 0.2891
 flow area 0.3386 0.3280 0.3007
 0 absolute flow angle 18.7592 58.1214 31.4886
 relative flow angle 65.7698 48.5047
 incidence 23.0698 17.7214
 deviation 16.8047 14.4886
 diffusion ratio 3.6611 2.6438
 momentum thickness 0.1380 0.0191
 omega (gas) 0.17676 0.01646
 omega (total) 0.20246 0.03734
 d1 dwakem,v3= 600.000 402.869
 d2 dwakem,sdelv1= 600.000 18.9275
 d3 dwakem,sdelv2= 400.076 0.
 n,ddave(n-2)(n)= 4 600.000 0.
 nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.08616 0.12958 0.06140 0.00584
 0.01213 0.00000 0.00000 20.00000 600.00000 400.07565
 nhg ds dl dlge dsll amlge amsll= 0.00000 0.00000 465.06369 4.43073 0.01798 0.27715
 nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.08616 0.12958 0.06140
 0.00584 0.01213 4.43073 465.06369 20.00000 600.00000 400.07565
 n,ddave(n-1)(n)= 4 472.147 465.064
 n,ddave(n-1)(n)= 4 472.147 465.064
 xnp,tg(3),p(3)= 3.20075E+10 667.135 2594.51
 1 ***** initial flow coefficient= 0.450 (istage= 1)

 0 stage total pressure ratio= 1.33462
 stage total temperature ratio= 1.10820
 stage adiabatic efficiency= 0.78907
 stage 1 total ETA 0.78907del T 65.13525
 Opsi= 5.4574E-01 psi1= 4.3063E-01 loss= 1.1511E-01
 0 **stage inlet** **stage outlet** **stage outlet**
 (before inter- (after inter-
 stage adjust- stage adjust-
 ment) (ment)
 xv= 0.01126 0.01126 0.01308
 xw= 0.00000 0.00000 0.00000
 xww= 0.04000 0.04000 0.03818
 xf= 0.00007 0.00007 0.00225

xwt=	0.04000	0.04000	0.03818
xair=	0.94874	0.94874	0.94874
xmetan=	0.00000	0.00000	0.00000
xgas=	0.96000	0.96000	0.96182
wmass=	0.00000	0.00000	0.00000
wwmass=	0.29512	0.29512	0.28170
fmmass=	0.05556	0.05556	0.16966
wtrmass=	0.29512	0.29512	0.28170
amass=	6.99987	6.99987	6.99987
chmass=	0.00000	0.00000	0.00000
vmass=	0.08306	0.08306	0.09648
gmass=	7.08293	7.08293	7.09635
tmass=	7.37806	7.37806	7.37806
ws=	0.01187	0.01187	0.01378
rhoa=	0.06054	0.06216	0.06484
rhom=	0.05619	0.06428	0.07118
rhog=	0.05691	0.06171	0.06847
tg=	602.00000	667.21460	667.13525
tw=	597.00000	597.00000	597.00000
tww=	597.00000	597.00000	597.44580
nhg: tragas, trawat =	1.10820	1.00075	
p=	1944.00000	2608.48193	2594.51001
tb=	667.26837	0.00000	681.50610
tdew=	518.09930	526.80371	531.09418
writing to external plot files			
clear(2)=	1.00000E-03		
nhg main start calculations for stage 2			
d1 dwakem,w2=	0.	585.055	
d2 dwakem,rdelv1=	600.000	18.8394	
d3 dwakem,rdelv2=	363.792	0.	
ddave(n-2)(n)=	5	472.147	0.
nhg wicsiz wmasss wmassl aming1 2 3 dl,ds,d1,d2,d3 =	0.00000	0.14085	0.00000 0.02855
0.11230 0.00000 0.00000 0.00000 600.00000 363.79233			
nhg ds dl dlge dsll amlge amsll=	0.00000	0.00000	411.66669 0.00000 0.14085 0.14085
nhg wicsiz wmasss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 =	0.00000	0.14085	0.00000
0.02855 0.11230 0.00000 411.66669 0.00000 600.00000 363.79233			
filmas(2) =	0.476775		
ui =	30.7086		
hhc =	0.718209		
htotl =	7.18209E-04		
n,ddave(n-1)(n)=	5	465.064	411.667
n,ddave(n-1)(n)=	5	465.064	411.667
1 ***** initial flow coefficient= 0.450 (stage= 2) *****			
0 stage total pressure ratio=	1.17666		
stage total temperature ratio=	1.06177		
stage adiabatic efficiency=	0.76247		
0 stage flow coefficient=	0.293		
axial velocity=	348.37		
rotor speed=	1188.42		
0	*rotor inlet*	*rotor outlet*	*stator outlet*

total pressure 2594.5100 3081.0574 3052.8523
 static pressure 2404.7615 2649.0469 2846.5596
 total temperature(gas) 667.1353 708.3432 708.3432
 static temperature(gas) 652.9359 679.7630 695.0020
 static density(gas) 0.0685 0.0724 0.0761
 static density(mixture) 0.0712 0.0753 0.0792
 0 axial velocity 348.3744 347.8579 330.9785
 absolute velocity 408.5336 591.0604 404.3733
 relative velocity 808.7470 585.0549
 blade speed 943.2569 948.2653 0.0000
 tang. comp. of abs. vel. 213.3892 477.8569
 tang. comp. of rel. vel. 729.8677 470.4084
 acoustic speed 1231.5189 1256.5637 1269.8992
 absolute mach number 0.3317 0.4704 0.3184
 relative mach number 0.6567 0.4656
 0 flow coefficient 0.2931 0.2927 0.2785
 flow area 0.2975 0.2816 0.2816
 0 absolute flow angle 31.4886 53.9471 35.0653
 relative flow angle 64.4843 53.5178
 incidence 18.8843 9.9971
 deviation 22.9178 17.2153
 diffusion ratio 3.8691 3.3655
 momentum thickness 0.0829 0.0355
 omega (gas) 0.13046 0.04166
 omega (total) 0.15583 0.06932
 d1 dwakem,v3= 600.000 404.373
 d2 dwakem,sdelv1= 600.000 18.8394
 d3 dwakem,sdelv2= 342.674 0.
 n,ddave(n-2)(n)= 6 465.064 0.
 nhg wicsiz wmassss wmassl aming1 2 3 dl,ds,d1,d2,d3 = 0.09618 0.12391 0.04467 0.00517
 0.01177 0.00000 0.00000 20.00000 600.00000 342.67392
 nhg ds dl dlge dsll amlge amsll= 0.00000 0.00000 421.20795 3.37468 0.01694 0.26476
 nhg wicsiz wmassss wmassl aming1 2 3 dsll,dlge,d1,d2,d3 = 0.09618 0.12391 0.04467
 0.00517 0.01177 3.37468 421.20795 20.00000 600.00000 342.67392
 n,dave(n-1)(n)= 6 0. 3.37468
 n,ddave(n-1)(n)= 6 411.667 421.208
 n,dave(n-1)(n)= 6 0. 3.37468
 n,ddave(n-1)(n)= 6 411.667 421.208
 xnp,tg(3),p(3)= 3.20075E+10 708.218 3052.85
 xnp,tg(3),p(3)= 3.05521E+10 708.218 3052.85
 1 ***** initial flow coefficient= 0.450 (istage= 2)
 ****=
 0 stage total pressure= 1.17666
 stage total temperature ratio= 1.06158
 stage adiabatic efficiency= 0.76428
 stage 2 total ETA 0.77133del T 41.08319
 0psi= 8.9614E-01 psi1= 6.9122E-01 loss= 2.0492E-01
 0 **stage inlet** **stage outlet** **stage outlet**
 (before inter- (after inter-
 stage adjust- stage adjust-
 ment) ment)

xv=	0.01308	0.01308	0.01789
xw=	0.00000	0.00000	0.00000
xww=	0.03818	0.03818	0.03337
xf=	0.00225	0.00225	0.00632
xwt=	0.03818	0.03818	0.03337
xair=	0.94874	0.94874	0.94874
xmetan=	0.00000	0.00000	0.00000
xgas=	0.96182	0.96182	0.96663
wmass=	0.00000	0.00000	0.00000
wwmass=	0.28170	0.28170	0.24623
fmmass=	0.16966	0.16966	0.47678
wtmass=	0.28170	0.28170	0.24623
amass=	6.99987	6.99987	6.99987
chmass=	0.00000	0.00000	0.00000
vmass=	0.09648	0.09648	0.13196
gmass=	7.09635	7.09635	7.13183
tmass=	7.37806	7.37806	7.37806
ws=	0.01378	0.01378	0.01885
rhoa=	0.07291	0.07330	0.07230
rhom=	0.05619	0.07557	0.07862
rhog=	0.06847	0.07269	0.07600
tg=	667.13525	708.34320	708.21844
tw=	597.00000	597.00000	597.00000
tww=	597.44580	597.44580	598.18591
nhg: tragas, trawat =	1.06158	1.00124	
p=	2594.51001	3081.05737	3052.85229
tb=	681.50610	0.00000	690.75311
tdew=	531.09418	530.05609	539.78143

writing to external plot files

***** overall performance *****

0 initial flow coefficient=0.450

0 corrected speed= 8879.0 1.000 fraction of design corrected speed

0 initial water content(small droplet)=0.000

initial water content(large droplet)=0.040

initial water content(total)=0.040

initial relative humidity=100.0 per cent

initial methane content=0.000

0 compressor inlet total temperature= 602.00

0 compressor inlet total pressure= 1944.00

0 corrected mass flow rate of mixture= 123.94

0 corrected mass flow rate of gas phase 118.99

0 overall total pressure ratio= 1.5704

0 overall total temperature ratio=1.1764

0 overall adiabatic efficiency=0.7729

***** performance of fan,lpc,hpc *****

0 gas phase stagnation stagnation adiabatic

0 corrected pressure temperature efficiency

0 mass flow ratio ratio

0 fan 0.0000 0.0000 0.0000 0.0000

0 lpc 0.0000 0.0000 0.0000 0.0000

0 hpc 0.0000 0.0000 0.0000 0.0000

0psi= 9.1336E-01 psi1= 7.0596E-01 loss= 2.0739E-01
i= 55

Number of loops = 100

total mass = 0.378182

0psi= 9.1336E-01 psi1= 7.0596E-01 loss= 2.0739E-01

i= 55

gemach = 0.273104

APPENDIX E

File 6: blheat3.out

Compressor flow adiabatic

initial clearance at ref.temp. (R)= 518.700

stage 1 : clearance[in]= 7.00092E-03

stage 2 : clearance[in]= 6.99997E-03

initial steady thermal node and blade clearance

node no. Node temp.(K):

1 3.0957E+02	2 3.1387E+02	3 3.1467E+02	4 3.0996E+02	5 3.1591E+02	6 3.1536E+02	7 3.1469E+02	8 3.2398E+02
9 3.1757E+02	10 3.2224E+02	11 3.2962E+02	12 3.4331E+02	13 3.3565E+02	14 3.3425E+02	15 3.5303E+02	16 3.2337E+02
17 3.2321E+02	18 3.5220E+02	19 3.2239E+02					

stage 1 : clearance[in]= 4.82655E-03

stage 2 : clearance[in]= 1.40285E-03

jsweep= 1

i,T(K):

1 3.0992E+02	2 3.1436E+02	3 3.1634E+02	4 3.1852E+02	5 3.3901E+02	6 3.1566E+02	7 3.1471E+02	8 3.2444E+02
9 3.3160E+02	10 3.2711E+02	11 3.5678E+02	12 3.6971E+02	13 3.3610E+02	14 3.3426E+02	15 3.5800E+02	16 3.3190E+02
17 3.3556E+02	18 3.7663E+02	19 3.8593E+02					

stage 1 : clearance[in]= 3.95489E-03

stage 2 : clearance[in]= 2.67029E-05

jsweep= 10

stage 1 : clearance[in]= 3.89576E-03

stage 2 : clearance[in]= -3.91006E-05

jsweep= 20

stage 1 : clearance[in]= 3.93009E-03

stage 2 : clearance[in]= -6.67572E-06

jsweep= 30

stage 1 : clearance[in]= 3.89862E-03

stage 2 : clearance[in]= -3.71933E-05

jsweep= 40

stage 1 : clearance[in]= 3.92628E-03

stage 2 : clearance[in]= -1.23978E-05

jsweep= 50

stage 1 : clearance[in]= 3.89957E-03

stage 2 : clearance[in]= -3.71933E-05

jsweep= 60

stage 1 : clearance[in]= 3.92246E-03
stage 2 : clearance[in]= -1.62125E-05

jsweep= 70
stage 1 : clearance[in]= 3.89957E-03
stage 2 : clearance[in]= -3.71933E-05

jsweep= 80
stage 1 : clearance[in]= 3.91865E-03
stage 2 : clearance[in]= -2.00272E-05

jsweep= 90
stage 1 : clearance[in]= 3.90053E-03
stage 2 : clearance[in]= -3.71933E-05

jsweep= 100
i,T(K):
1 3.1010E+02 2 3.1475E+02 3 3.1708E+02 4 3.1948E+02 5 3.3932E+02 6
3.1580E+02 7 3.1473E+02 8 3.2468E+02
9 3.3161E+02 10 3.2908E+02 11 3.5725E+02 12 3.7011E+02 13 3.3636E+02 14
3.3428E+02 15 3.6021E+02 16 3.3192E+02
17 3.4101E+02 18 3.7951E+02 19 3.8587E+02
stage 1 : clearance[in]= 3.91674E-03
stage 2 : clearance[in]= -2.38419E-05

Appendix F: Sample Data for Thermal Load and Clearance Program

The following set of data are for the nodal temperature distribution and blade clearance program, to which texts have been added after semi-colon to explain properly (*in actual data file these explanations are not there*).

```
2 0 7 4 1 ; no.of stages, no.of fan stages, max.no.of nodes per stage,  
; max.no.of adjacent nodes, type of rotor intern.cooling  
; IGV has 4 centrod node  
2 4 2.4145E+02 ; IGV 1: node type, no.of adj.nodes, heat capacity [J/K]  
-75 6 -72 -76 ; node numbers  
9.2520E-04 9.2520E-04 2.7860E-03 2.4660E-03 ; Sij [m2]  
4.7800E-04 7.6910E-04 2.7710E-04 2.7710E-04 ; lS [m2-K/W]  
12 4 1.6219E+02 ; for IGV2, same as IGV1  
-75 3 -73 -72  
2.6280E-03 2.6280E-03 1.4020E-03 1.2260E-03  
1.2460E-04 2.8170E-04 2.4930E-04 2.4930E-04  
14 4 2.0453E+02 ; for IGV3, same as IGV1  
2 9 -73 4  
2.6280E-03 2.6280E-03 1.7680E-03 1.5460E-03  
2.8170E-04 5.4300E-04 2.4930E-04 3.5380E-03  
6 2 1.3700E+01 ; for IGV4, same as IGV1  
3 -72  
1.5460E-03 1.0350E-02  
3.5380E-03 5.6540E-04  
7 ; no. of centroid nodes in stage 1  
; stage 1, centroid node 1:  
6 2 3.4170E+01 ; node type, number of adjacent nodes, heat capacity  
6 -71 ; node numbers  
1.3520E-03 2.1190E-02 ; Sij [m2]  
5.0520E-03 6.8900E-05 ; lS [m2-K/W]  
; stage 1, centroid node 2:  
11 4 1.1540E+02  
1 8 5 7  
9.2520E-04 9.2520E-04 1.3520E-03 1.1580E-03  
7.6910E-04 8.2630E-04 5.0520E-03 2.7710E-04  
; stage 1, centroid node 3:  
15 2 1.1943E+02  
6 -76  
1.1580E-03 3.1290E-03  
5.0530E-04 1.9404E-04  
; stage 1, centroid node 4:  
2 4 2.8021E+02  
6 13 -72 -76  
9.2520E-04 1.1820E-03 3.0470E-03 2.6320E-03  
8.2630E-04 9.0380E-04 2.7710E-04 2.7710E-04  
; stage 1, centroid node 5:  
12 4 5.8508E+02  
3 10 -73 -71  
2.6280E-03 3.4610E-03 4.9390E-03 4.3270E-03
```


3.0260E-04 1.2460E-04 2.4930E-04 2.4930E-04

; for Reynolds number and Nusselt number calculations upstream and downstream axial ;
lengths are required. These are given (*in inches*) for all global nodes, so long they are rel- ; evant
(otherwise put equal to zero), first for casing in one line, followed by rotor in ano-; ther line in
the following:

0.0000E+00 0.0000E+00
0.0000E+00 2.8380E+00
0.0000E+00 1.0000E+00
0.0000E+00 0.0000E+00
1.0000E+00 2.2610E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
2.8380E+00 4.6660E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
4.6660E+00 7.8440E+00
2.2610E+00 5.3560E+00
0.0000E+00 0.0000E+00
5.3560E+00 7.0160E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
7.8440E+00 1.0033E+01
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
1.0033E+01 1.3322E+01
7.0160E+00 1.0793E+01
0.0000E+00 0.0000E+00
1.0793E+01 1.2222E+01
0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00
1.2222E+01 1.3222E+01
0.0000E+00 0.0000E+00

1.17600E-05 ; casing material thermal expansion coefficient (K^{-1})

; for stage 1: how many thermal expansion nodes are there (excluding casing), global node ;
number on casing, casing radius (*in inches*), rotor disk internal radius (*in inches*):

2 9 14.489 2.950

5 6 ; global node numbers being considered (excluding casing)

8.4100E-06 1.1760E-05 ; corresponding coeff. of thermal expansion (K^{-1})

7.5200E+00 6.9500E+00 ; corresponding radial lengths (*in inches*)
; for stage 2 (similar to stage 1):

2 16 14.257 3.640
12 13
8.4100E-06 1.1760E-05
6.6000E+00 7.6400E+00